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PHYSICAL PROPERTIES OF RECYCLED ABS BLENDED WITH VIRGIN ABS

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อภิชาติ ภาควิธี: สมบัติทางกายภาพของรีไซเคิลเอบีเอสผสมกับเอบีเอสใหม่ (PHYSICAL PROPERTIES OF RECYCLED ABS BLENDED WITH VIRGIN ABS) อ. ที่ปรึกษา: รศ. ดร. อมร เพชรสม, อ.ที่ปรึกษาร่วม: นายปฏิพล ธาดากร, 64 หน้า.

วัตถุประสงค์หลักของงานวิจัยนี้เพื่อศึกษาสมบัติด้านต่าง ๆ ของพลาสติกรีไซเคิลเอบีเอสซึ่งนำกลับมาใช้ใหม่ เพื่อนำมาใช้เป็นข้อมูลสำหรับผู้ผลิตชิ้นส่วนพลาสติก ABS ในอุตสาหกรรม โดยศึกษาสมบัติต่าง ๆ 2 กรณี ดังนี้ ในกรณีแรกมุ่งศึกษาเม็ดบดที่ผ่านกระบวนการผลิตแบบฉีด ตั้งแต่ 1-6 รอบ กระบวนการผลิตจะถูกนำมาศึกษาโดยรีไซเคิลเอบีเอสในแต่ละรอบที่นำมาศึกษาสมบัติทางกายภาพนั้น การเร่งสภาวะจะถูกจำลองขึ้นที่อุณหภูมิ 90 องศาเซลเซียส 72 ชั่วโมง เพื่อจำลองสภาวะการใช้งาน 1-2 ปี จากผลการทดลองพบว่าที่รอบการผลิตมากขึ้นจะมีผลกระทบต่อสมบัติทางกายภาพ อาทิเช่น ค่าดัชนีการไหลลดลงเล็กน้อย ค่าการทนแรงกระแทกลดลงชัดเจน ค่าความเครียดลดลง ค่าความทรงรูปสูงขึ้น และค่าอุณหภูมิกลาสแทรนซิชันเพิ่มขึ้น และจากการทดลองในกรณีแรกนั้นจะแสดงการเสื่อมสภาพของพอลิเมอร์ระหว่างกระบวนการผลิตโดยจะเปลี่ยนโครงสร้างของโมเลกุล อาทิ ความหนืดและสมบัติเชิงกล ดังนั้นจึงมีการผสมเม็ดพลาสติกที่ใช้แล้วเข้ากับเม็ดใหม่ที่ยังไม่ผ่านกระบวนการขึ้นรูปมาก่อน เพื่อปรับปรุงสมบัติทางกายภาพของพลาสติกที่ใช้แล้วให้ดีขึ้น ดังนั้นในกรณีที่สองจะใช้เม็ดหลอมจากการขึ้นรูปครั้งที่ 6 ผสมกับเอบีเอสเม็ดใหม่ในอัตราส่วนต่างๆ ของกระบวนการผลิตโดยปรับอัตราส่วนผสมตั้งแต่ 0, 20, 40, 60, 80 และ 100 เปอร์เซ็นต์โดยน้ำหนัก จากผลการทดลองพบว่าเมื่อปริมาณหรืออัตราส่วนของเม็ดหลอมมากขึ้นสมบัติทางกายภาพ อาทิเช่น ค่าดัชนีการไหลลดลงเล็กน้อย ค่าการทนแรงกระแทกลดลงชัดเจน ค่าความเครียดลดลง ค่าความทรงรูปสูงขึ้น และค่าอุณหภูมิกลาสแทรนซิชันเพิ่มขึ้น

สาขาวิชา ปิโตรเคมีและวิทยาศาสตร์พอลิเมอร์ ลายมือชื่อนิสิต
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The objective of this research is the investigation of recycled ABS which was reused. This work will be used as information for the plastic manufacturing industry. The study was separated into two cases. First, the regrind from injection manufacturing process 1st – 6th recycled will be investigated and the physical properties of each recycled ABS will be studied. Aging condition was carried out at 90 °C 72 hrs in order to simulate one to two years of actual use. It was found that increasing number of generations has effect on the physical properties such as, melt flow index slightly decreases, impact strength clearly decreases, elongation at break decreases, flexural strength and flexural modulus and glass transition temperature increase. Degradation of polymer from the manufacturing process will transform the molecular structure such as viscosity, mechanical properties etc. Consequently, the sample was blended between virgin with 6th recycled ABS to improve the physical properties. Second, the repelletized resin obtained from 6th recycled ABS was blended with the ratio of 0, 20, 40, 60, 80 and 100% by weight of virgin material. It was found that increasing quantity or ratio of repelletized resins has effect on the physical properties such as, melt flow index slightly decreases, impact strength clearly decreases, elongation at break decreases, flexural strength and modulus increase and glass transition temperature increases.

Field of study Petrochemistry and Polymer Science Student's signature ....
Academic year 2007 Advisor's signature ....
Co-Advisor's signature ....

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LIST OF ABBREVIATIONS

ABS : Acrylonitrile butadiene styrene terpolymer

ABS#6RP : The repelletized resin from the 6th recycled ABS

DSC : Differential scanning calorimeter

EL : Elongation at break

FS : Flexural strength

FM : Flexural modulus

HDT : Heat distortion temperature

HR : Rockwell hardness

MFI : Melt flow index

NI : Notched impact

SAN : Styrene acrylonitrile copolymer

SEM : Scanning electron microscopy

T_g : Glass transition temperature

TS : Tensile strength

°C : Degree celsius

CHAPTER I

INTRODUCTION

1.1 Introduction

The recycling of polymeric materials has attracted considerable interest in the processing industry. The lack of such an understanding means that it is not possible to relate specification of materials to expected product performance.

Acrylonitrile-Butadiene-Styrene terpolymer (ABS) is one of the most successful engineering thermoplastics. ABS consists of styrene-acrylonitrile copolymer (SAN) mixed with and to some extent grafted to polybutadiene rubber. ABS is created as resins (with the harmony of hardness and softness) by improving the brittleness, which is the disadvantage of polystyrenes, through addition of a rubber component while maintaining hardness and fluidity, which are the advantages of polystyrenes. As is well known, ABS resins are one type of excellent resin having all the desirable properties, including impact resistance, process ability, gloss properties, good mechanical properties, and high heat distortion temperature.

ABS resins have been used in very broad fields of application and particularly in many aspects of daily life. At present, the amount used has gradually increased.

ABS is widely used in the automotive industry, telecommunications, business machine and consumer product, mainly because both the properties and price are intermediate between the lower priced commodity thermoplastic and the more expensive high performance engineering plastics. For this reasons ABS is also an interesting plastic material for recycling [1].

The degradation of plastic material in conventional use can be regarded as the sum of all types of aging effects occurring during the product life cycles, both degradation in manufacturing processes and aging during usage [2]. The changes in properties of ABS during a series of subsequent recycling should be used to make process adjustment during manufacturing process.

1.2 Purposes of research

1. The physical properties of recycled ABS plastic during six cycles of accelerated aging.
2. The physical properties of various blends of the sixth recycled ABS and virgin grade ABS will also investigated.

1.3 Scope of investigation

The investigation was carried out as follows:

1. Literature review.
2. Preparation of recycled ABS.
    - a) Preparation of the ABS recycled from virgin ABS by regrinding and accelerated aging to the 1st- 6th recycled.
    - b) Preparation of various blend of ABS recycled#6 with virgin at various ratios of 100/0, 80/20, 60/40, 40/60, 20/80, 0/100 percent by weight.
3. Characterization of the samples.
    - a) Rheological behavior
        - Melt flow index ASTM D1238
    - b) Mechanical properties
        - Izod Notched Impact Strength ASTM D256
        - Tensile strength ASTM D638
        - Elongation at break ASTM D638
        - Flexural modulus ASTM D790
        - Flexural strength ASTM D790
        - Rockwell hardness ASTM D785
        - Heat distortion temperature ASTM D648
    - c) Thermal properties
        - Differential Scanning Calorimeter ASTM D3417
    - d) Characterization of the sample morphology by SEM
4. Summarizing the results and writing the thesis.

CHAPTER II

THEORY AND LITERATURE REVIEW

2.1 Acrylonitrile butadiene styrene

ABS polymers are a family of opaque thermoplastic resins by copolymerization of acrylonitrile-butadiene-styrene. The ABS materials were grafted polymer, formed by polymerization of resin monomers, styrene and acrylonitrile, in the presence of a rubbery polybutadiene. The composition of ABS material consists of phase of grafted ABS dispersing in SAN matrixes. These are the copolymerization step of acrylonitrile and styrene monomer on the polybutadiene rubber.

The characteristic properties of ABS resins are strongly affected by molecular characteristics of the styrene/acrylonitrile (SAN) copolymer forming the butadiene phase and the matrix.

The method for preparing grafted ABS are classified into three types, where mass and emulsion polymerization and mass suspension method have been widely used in industry.

Among those methods in general, the emulsion polymerization method has been mainly used. In the case of the SAN copolymer, it has been prepared by either emulsion polymerization or bulk polymerization.

2.1.1 Manufacturing of ABS [3]

The commercial production of ABS formulations is accomplished by a number of different methods based on free radical polymerization. The two main methods based on emulsion or solution polymerization techniques. Most of the ABS is made using the emulsion process.

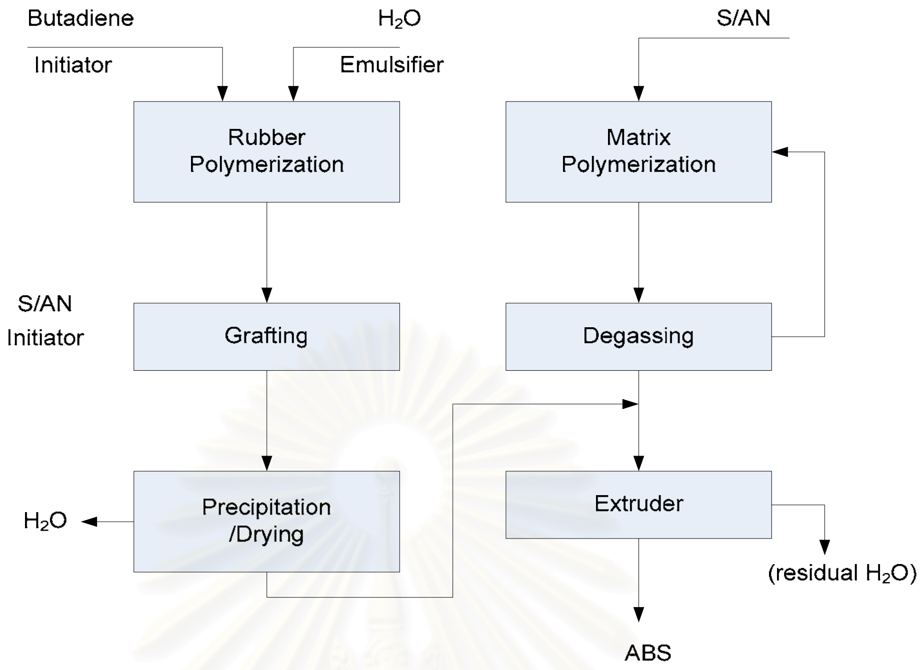


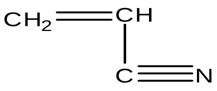
Figure 2.1 Scheme of emulsion process.

Although more complicated than the mass process, emulsion polymerization is still widely used because of its greater flexibility. The first step is the preparation of the rubber latex using emulsifiers. The crosslinking of the rubber occurs simultaneously during polymerization and is controlled by initiator level, chain transfer agent and process condition. It is common to increase the particle size by agglomeration thereby achieving a reduction in cycle time.

The next step is the polymerization of styrene and acrylonitrile in the presence of the rubber latex. Part of the polymerized styrene-acrylonitrile is grafted onto the rubber. This grafted rubber concentrate is then either mixed with additional emulsion-prepared styrene-co-acrylonitrile (SAN) copolymer and then coagulated or first isolated and then compounded with SAN.

2.1.2 Component of ABS [1]

ABS resins are generally prepared in the compositional ratio of 21-27% acrylonitrile, 12 – 25% butadiene and 54 – 63% styrene on average, where styrene give good processability and stiffness to the final ABS, butadiene improve the impact strength, and acrylonitrile improve the chemical resistance.

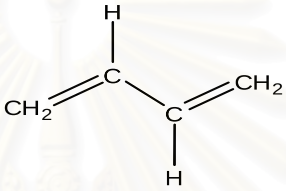


acrylonitrile

Figure 2.2 Structure of acrylonitrile.

2.1.2.1 Qualification of acrylonitrile as follows;

- Chemical resistance
- Fatigue resistance
- Hardness and rigidity

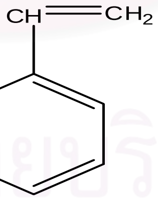


1,3-butadiene

Figure 2.3 Structure of butadiene.

2.1.2.2 Qualification of butadiene as follows;

- Low-temperature ductility
- Impact resistance
- Melt strength



styrene

Figure 2.4 Structure of styrene.

2.1.2.3 Qualification of styrene as follows;

- Heat resistance
- Processing ability
- Coloring
- Hardness and rigidity

2.2 Processing stability [4]

The influence of processing on properties is determined by base polymer characteristics, processing conditions, and the presence of additives and impurities, including absorbed water.

Base polymer characteristics are determined by the specific emulsion, suspension, or bulk-polymerization manufacturing, and by the resin structure and composition.

Processing conditions could influence resultant properties by chemical and physical means. Chemical changes may be induced by exposure of the polymer to shear and high temperature; degradation may be thermal or oxidative under processing conditions. Degradation during processing that leads to loss of impact has been attributed to degradation of the polybutadiene phase and, under most severe molding conditions, to degradation of the matrix phase. Morphological changes may become evident as agglomeration of dispersed polybutadiene particles during injection molding at 280 °C. Physical effects will be superimposed upon chemical changes; orientation and molded in stress can have marked effects on mechanical properties. Thus, proper selection and control of process variables are important to maintain optimum performance in molded parts. Antioxidants added at the compounding step have been shown to help retention of physical properties upon processing. For example, the addition of 0.5 parts of the conventional antioxidant 2,6-di-t-butyl-4-methylphenol (BHT) helps minimize impact loss from extended milling at 205 °C.

Appearance changes evident under certain processing conditions include color development, changes in gloss. Inherent color stability depends on the resin structure, composition, and manufacturing technique. Discoloration may be minimized reducing stock temperatures during molding or extrusion. Splaying is the formation of surface imperfections elongated in the direction of flow in molded parts and is most commonly caused by residual moisture in the polymer; the severity of splay varies with molding conditions. Moisture-induced splay may be prevented by following proper drying procedures. Other causes of splay include occluded air and gaseous degradation products.

2.3 Thermal oxidative stability [4]

The thermally initiated degradation of polymeric materials in the presence of oxygen usually proceeds by an autocatalytic free-radical chain mechanism. The polymeric components of ABS differ in oxidative stability. Studies have been conducted on ABS to determine the structural feature most sensitive to oxidation, the relationship of oxidation to property changes, and the effects of additives. Antioxidants have been shown to substantially improve oxidative stability.

The rate of the oxidation process may be directly determined by measuring the quantity of oxygen consumed in an oxygen-absorption apparatus. Comparisons of the rate of oxidation of ABS with polybutadiene and styrene-acrylonitrile copolymer indicate the following ranking in order of decreasing oxidation rate at 120 ^{o}C: polybutadiene > ABS > styrene-acrylonitrile copolymer. Thus, it is indicated that the rubber phase in ABS oxidizes more rapidly than the rigid component. Oxidation of polybutadiene under these conditions results in embrittlement of the rubber owing to cross-linking. Such embrittlement of the elastomer in ABS would reduce impact resistance. Spectroscopic studies show changes occur in the rubber phase upon oven aging. Infrared examination indicates disappearance of double-bond content associated with the polybutadiene component and the corresponding development of carbonyl and hydroxy functions. No significant change is evident in spectral characteristic of the nitrile or phenyl substituents with whole polymer analysis.

Pigmentation can adversely affect thermal oxidative stability. Metals such as iron, copper, manganese, and cobalt are present in pigments and appear to be capable of catalyzing oxidation. The effects of pigments on stability as determined by oxygen absorption at elevated temperatures were shown to correlate well with embrittlement determined by a change in a mechanical property.

Studies indicate that embrittlement of the rubber during oxidation may not be the only factor contributing to mechanical property changes. The mechanism of polybutadiene oxidation involves both cross-linking and chain-scission processes. If the chain-scission process results in the detachment of grafted styrene-acrylonitrile copolymer, then impact properties would substantially deteriorate. Although whole polymer analysis may not indicate a substantial change in nitrile absorption upon oxidation, examination of the grafted portion indicates a substantial decrease in nitrile content. These results suggest that oxidative degradation of the grafted polybutadiene component can cause property loss because of cross-linking of the polybutadiene producing embrittlement and chain scission resulting in cleavage of the grafted copolymer from the rubber phase.

The thermal oxidation of ABS becomes diffusion-limited with increasing sample thickness. Examination of oven-aged samples has shown that substantial degradation is limited to the outer surface; the thickness of the degraded layer depends on the time and temperature of exposure. Oxidation rates also indicate dependence on sample thickness. Impact properties, as determined by high speed puncture tests, are sensitive to the thickness of the degraded layer. Under the high speed puncture impact test conditions, the critical thickness of the degraded layer at which surface fracture changed from ductile to brittle is about 0.02mm. Removal of the degraded layer restores ductility.

Since oxidative degradation of ABS can result in embrittlement of the rubber component of detachment of the grafted copolymer from the rubber, stabilization efforts have been primarily concerned with the rubber component. Techniques such as differential scanning calorimeter, oxygen absorption, and spectroscopic determination of the carbonyl index have been used for stabilizer screening and reflect the contribution of the rubber component. The activities of various conventional antioxidants in ABS have been described.

The activity of additives may be limited if they are uniformly dispersed throughout the polymer matrix and it is the rubber component that is sensitive to degradation. The experimental use of rubber-bound stabilizers to permit concentration of the additive in the rubber phase has been described. Thus, it has been shown that certain antioxidants can react with ABS in the presence of a radical generator and chemically during processing to produce effectively stabilized polymers whose antioxidant protection is highly resistant to solvent extraction.

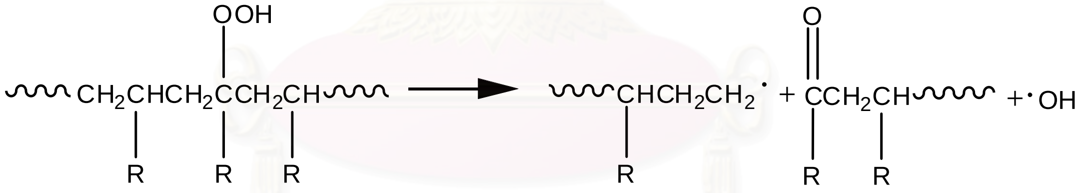
2.4 Polymer degradation [5]

Stability of polymers is of critical interest to manufacture and understandably polymer degradation reaction have received considerable attention There are three principal methods of degrading polymers : (1) chemical (2) thermal and (3) radiative.

2.4.1 Chemical degradation

This discussion is limited to reactions that cause breakdown of polymer backbone; it does not cover reactions involving pendant groups. Because the backbones of vinyl polymers are made up of carbon chains containing no functional groups other than the double bonds of diene polymers, chemical degradation is essentially limited to oxidation. Most important is oxidation with oxygen because this has a direct bearing on polymer durability.

Saturated polymers are degraded very slowly by oxygen, and the reaction is autocatalytic. It can be speeded up considerably by application of heat or light or by the presence of certain impurities that catalyze the oxidation process. Tertiary carbon atoms are most susceptible to attack, and this is reflected in the following order of resistance to oxidation of three common polymers: polyisobutylene > polyethylene > polypropylene. Reaction products are numerous and include water, carbon dioxide, carbon monoxide, hydrogen and alcohols. Crosslinking always accompanies degradation. It is believed that decomposition of initially form hydroperoxide group is mainly responsible for chain scission (as shown in Figure 2.5)



$$\sim CH_2\underset{R}{CH}CH_2\underset{R}{\overset{OOH}{C}}CH_2\underset{R}{CH}\sim \longrightarrow \sim\underset{R}{CH}CH_2CH_2^{\bullet} + \underset{R}{\overset{O}{\overset{\|}{C}}}CH_2\underset{R}{CH}\sim + {}^{\bullet}OH$$

Figure 2.5 Scheme of chemical degradation.

Unsaturated polymers undergo oxidative degradation much more rapidly by complex free radical processes involving peroxide and hydroperoxide intermediates. Allylic carbon atoms are most sensitive to attack because resonance-stabilized radical are formed, oxidation is inhibited in commercial polymers by addition of antioxidant.

2.4.2 Thermal degradation

Three types of thermal degradation are characteristic of vinyl polymer (1) non-chain scission (2) random chain scission (3) depropagation.

Non-chain scission refers to reactions involving pendant groups that do not break the polymer backbone. Typical of such reactions are dehydrochlorination of poly (vinyl chloride), elimination of acid from poly (vinyl esters) – for example, poly (vinyl acetate) and elimination of alkene from poly (alkyl acrylates). The first two reaction lead to highly colored residue, indicating that the double bonds formed in the polymer backbone are primarily conjugated (as shown in Figure 2.6).

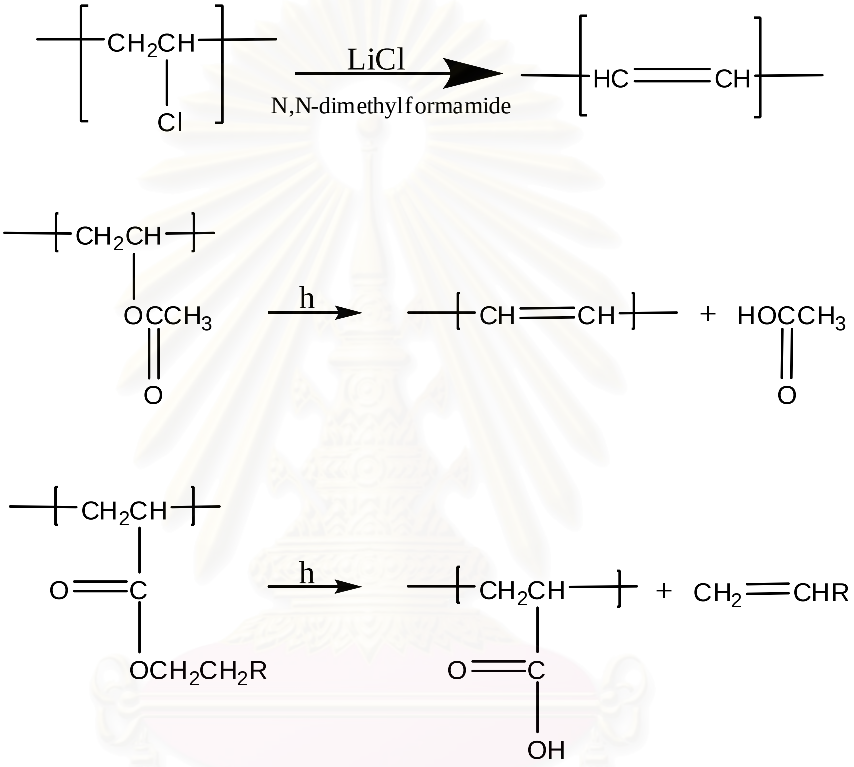


Figure 2.6 Scheme of non chain scission (not break the polymer backbone).

Non-chain scission reactions are useful for characterizing copolymers when the amount of volatile degradation product can be correlated with the concentration of a given repeating unit.

Random chain scissions result from hemolytic bond-cleavage reactions at the weak points in the polymer chains. Complex mixtures of degradation products are formed from the origin of which may be explained in terms of radical transfer reaction.

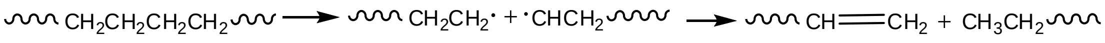


Figure 2.7 Scheme of random chain scission.

Series of triplet peaks corresponding to alkane,1–alkane, and α,ω-dialkene, with the largest peak in each triplet being that of 1-alkene. This follows from the breakdown pattern as shown in Fig 2.4. Random chain scission occurs with all vinyl polymer to varying degrees, but it occurs less with increasing substitution on the polymer backbone.

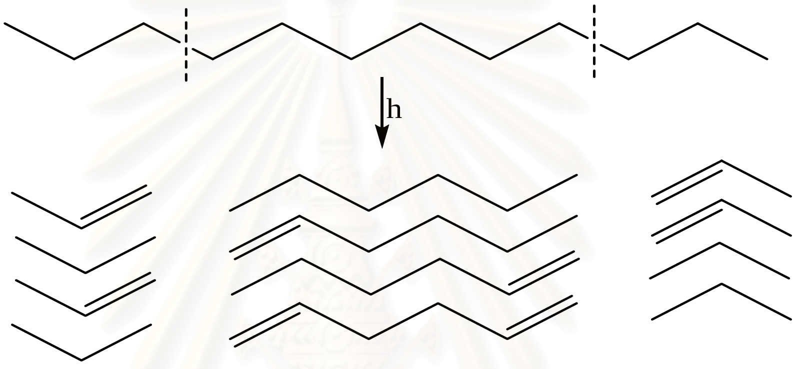
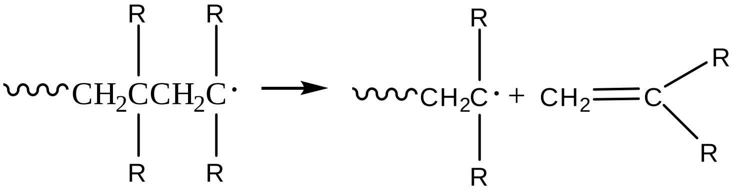


Figure 2.8 Scheme of chain scission of polyethylene.

Depropagation, or depolymerization (unzipping), to give monomer occurs mainly with polymers prepared from 1, 1-dissubstituted monomers. Initiation may be at a chain end or at a random site along the backbone. Poly (methyl methacrylate) appears to begin unzipping primary at the chain ends where as poly (α-methylstyrene) does so at random site along the chain. In both cases tertiary radicals are formed which each depropagation step. Polymers having single substituents on alternate carbons degrade by both depropagation and random chain scission, with the amount of monomer form varying with temperature.



$$\sim CH_2C(R)_2CH_2C(R)_2\cdot \longrightarrow \sim CH_2C(R)_2\cdot + CH_2{=}C(R)_2$$

Figure 2.9 Scheme of depropagation.

2.4.3 Degradation by radiation

It was mentioned earlier that radiation may cause both crosslinking and degradation. Which predominates depends on radiation dosage, polymer structure, and temperature. Ultraviolet or visible light causes 1, 1-dissubstituted polymers to degrade to monomer almost exclusive at elevated temperatures, whereas crosslinking and chain scission reactions regardless of temperature. Rearrangements may also occur as a result of homolysis and recombination reactions, especially with diene polymers.

2.5 Crosslinking [3]

During the grafting process, a radical site (addition/abstraction) is created on the rubber backbone. Propagation of styrene-acrylonitrile results in the SAN graft. The final step in the grafting sequence is termination of the radical site.

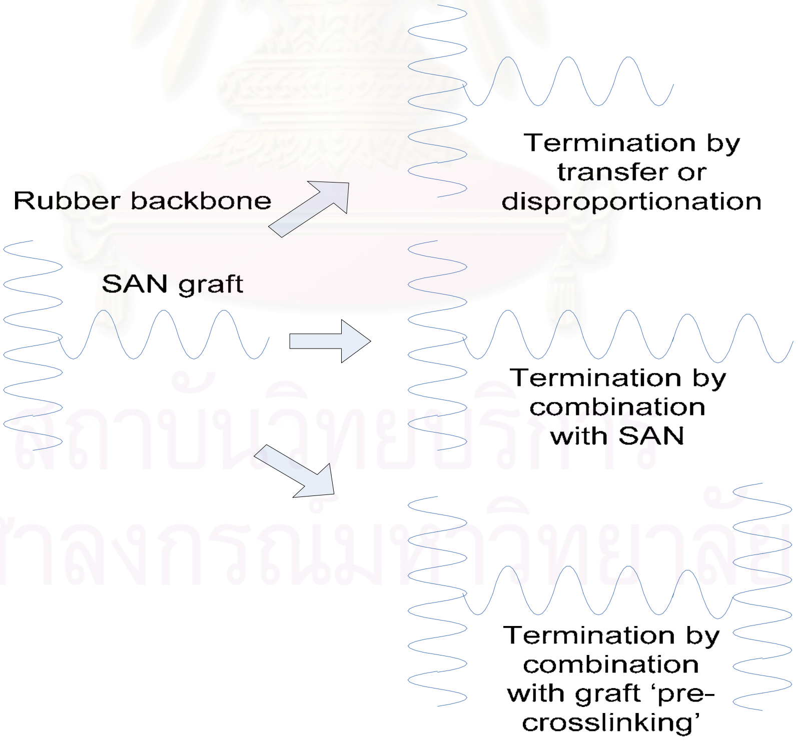


Figure 2.10 Termination processes during grafting.

Figure 2.6 gives an overview of the different possibilities. Chain transfer and disproportion result in a grafted rubber with 'normal' SAN molecular weight.

Termination by combination with a growing SAN chain also gives a grafted rubber but in this case the molecular weight of the graft is higher (double). A final possibility is combination with another growing graft. The result in this case is a crosslink between two rubber chains. This type of termination increases the molecular weight dramatically and will be reflected in the viscosity in the rubber phase. The viscosity of the rubber phase has a large influence on the sizing process that takes place during the production of ABS. As the viscosity ratio (rubber/SAN) increases, sizing will become more difficult.

2.6 Literature review

Nowadays, there are many interesting works in recycled plastic because they are a major cost reduction in industry such as automotive parts, electrical parts, toys and house-hold products etc.

Boldizar et al. [2] studied the degradation of ABS during repeated processing and accelerated aging. This research was studied the degradation of three series of ABS sample; a series of repeated extrusion, a series of aging cycle and a series of both repeated extrusion and aging cycle conditions. The aging condition at 90 ^{O}C for 72 hours could be simulated about 1-2 year normal usage at room temperature. The aim of this work was to study the effect between combination of extrusion processing and aging in air and comparing the effect between extrusion processing alone and aging alone too. The important effect was elongation and flow properties. For second to the sixth cycle, the elongation at break decreased in aging and increased in extrusion step. The melt volume rate remained constant in the extrusion as well as in the aging series but the melt volume rate in the combined series increased after the fourth cycle. Thermal oxidative in the extrusion series largely reduced in the aging series and even greater decreased in the combined series. CI increased in aging series and to a less extent in combined series but the CI remained rather constant in the extrusion series. They found no significant changes in the size and shape of the polybutadiene particle.

Xue et al. [6] studied the thermal degradation of a graft copolymer in which acrylonitrile grafted onto polystyrene by thermogravimetric analysis. The thermogravimetric analysis curves for polystyrene, polyacrylonitrile and poly(styrene-g-acrylonitrile) indicated that the degradation of polyacrylonitrile was occurred at the lowest temperature while those of the graft copolymer began at the highest temperature. These curves indicated that the polystyrene was stabilized by the acrylonitrile. It was observed that at higher temperatures the polyacrylonitrile was stabilized more than either poly(styrene-g-acrylonitrile) or polystyrene. The above result suggested that the grafted acrylonitrile underwent thermal degradation to give a layer that offered some thermal protection to the polystyrene. The data from TGA/FTIR showed that the degradation of polyacrylonitrile began first at higher temperature than in both polystyrene and copolymer SAN, and TGA/FTIR results confirmed that the appearance of degradation products of polystyrene were formed at a higher temperature in the graft copolymer than in polystyrene homopolymer.

Bastida et al. [7] studied the degradation of SAN as a consequence of repeated injection molding by FTIR, MFI and TS testing. The aim of this work was to study the chemical structure, MFI and mechanical properties of SAN after reprocessing. The FTIR technique did not show any change in chemical structure. The molecular weight decreased and MFI increased as a consequence of chain scission. The modulus of elasticity of SAN remained constant with reprocessing while tensile strength and ductility decreased. SAN became progressively yellow with reprocessing.

Tiganis et al. [8] studied the accelerated thermal degradation of ABS due to aging at high temperature (>80^{o}C). The impact resistance of specimen aging at 120^{o}C slightly decreased from the specimen aging at 90^{o}C and this reduction depended on surface property. This research indicated that surface degradation proceeded by chain scission and crosslinking in the PB phase. Dynamic mechanical thermal analysis supported the occurrence of crosslinking and crosslinking caused the increase in the glass transition temperature of the PB phase. Degradation in SAN phase was less significant than PB phase.

Shriver et al. [9] investigated the life-cycle value of an engineering plastic. This paper described the maximum amount of regrind and processing conditions required for blending virgin material with regrind of unknown history.

Blom et al. [10] studied DSC, mechanical testing and oxidation onset temperature that directly led to understanding of ABS degradation in production setting. Oxidation onset temperature testing and DSC analysis indicated a slight lower onset temperature and a higher glass transition temperature, respectively. The results demonstrated a reduction in mechanical properties because of degradation in butadiene phase.

Shriver et al. [11] studied the mechanical properties of injection molded recycled engineering plastics which involves recycling PC through 10 generations. Further experiments involved mixing the tenth generation material with varying proportion of virgin material. The results indicated that molecular weight decreased slightly over ten generations of processing and the melt flow index for PC was directly proportional to the number of regrind generations. PC mechanical properties were not significant change and yellowness increased as a regeneration number increased.

Suzuki et al. [12] investigated the thermal degradation of ABS by TGA/FTIR techniques. The degradation of ABS was compared with polystyrene, polybutadiene, polyacrylonitrile (PAN) and styrene-acrylonitrile copolymer (SAN). Investigation showed that the evolution of butadiene from ABS was found to commence at 340 ^{o}C, styrene at 350^{o}C and acrylonitrile at 400 ^{o}C.

CHAPTER III

EXPERMENTAL

3.1 Materials

ABS used in this work is in the form of pellets, it is a high flowing grade and the materials used in this study are commercial grade ABS produced in Thailand. Tradename is ABS Porene® gradeGA300 (MFI ~ 30 g/10min, Acrylonitrile Butadiene Styrene). ABS material is supplied by IRPC Co., Ltd.

3.2 Apparatus

- Injection mold machine (For test specimen): NESEI Model FS80S12 ASE
- Single screw injection machine (For sample): Toshiba IS100
- Grinder : OKANE-5HP Model B5HP
- Dehumidifier dryer (Accelerator condition) : KENPLAS Model SHD-100T
- Melt flow index tester : Yayeness Model 7054P/1
- Izod impact testing machine : ZWICK Model 5102.100/100
- Tensile strength testing : INSTRON Model 4302
- Flexural strength and flexural modulus Testing : ZWICK Model 1435.01
- Rockwell hardness : MATSUZAWA SEIKI Model DXT-1
- Heat distortion temperature : DAVENPORT
- Differential scanning calorimeter : PERKIN ELMER DSC7
- Scanning electron microscopy : JEOL Type JSM-6400
- Vented single screw extruder : ISHINAKA Model HS-50
- High speed mixer : KAWATA Model SMG100

3.3 Experimental

3.3.1 The physical properties of recycled ABS (1st – 6th generations)

The virgin ABS (about 4 kg) was used about to investigate the physical properties. The virgin ABS was transformed by the injection process to about 200 pieces specimens. Then grinding these specimens and accelerated aging of the grinding materials at 90 °C for 72 hours.

In the next step, the recycled#1 ABS (about 4 kg) was used to investigate the physical properties. The recycled#1 was transformed in the injection process to about 180 pieces specimens. Then grinding these specimens and accelerated aging of the grinding at 90 °C for 72 hours. Investigation of the physical properties in each recycled ABS is as follow. (as shown in Figure 3.1)

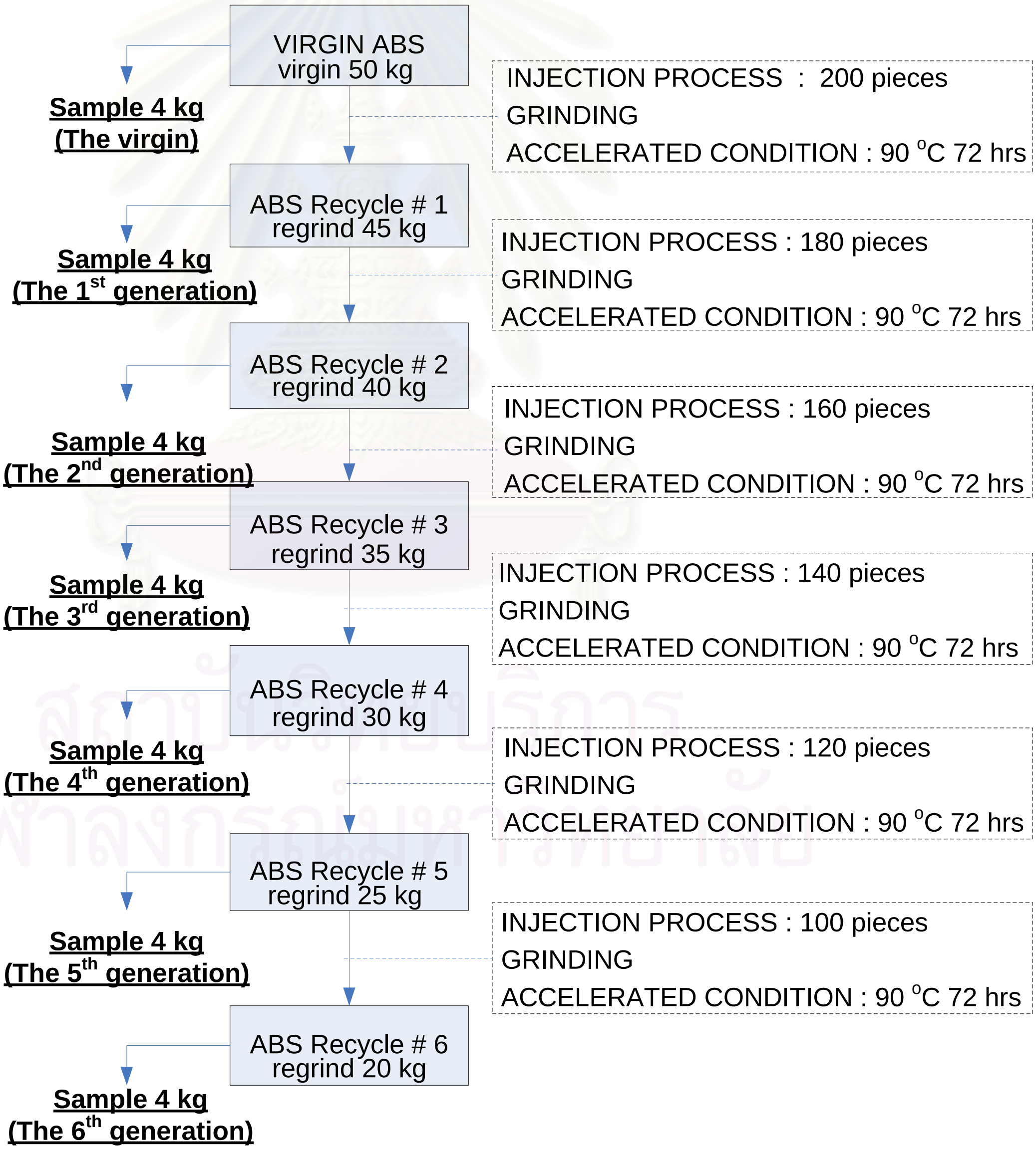


Figure 3.1 Schematic diagram for the preparation of recycled ABS (1st- 6th recycled).

3.3.2 The physical properties of recycled ABS#6 blended with virgin ABS

The recycled ABS#6 was blended with virgin ABS at various ratios and repelletized resin by the high speed mixer as follows: 100/0, 80/20, 60/40, 40/60, 20/80, 0/100 percent by weight (as shown in Figure 3.2). Then the physical properties of ABS#6RP blended with various ratio of virgin ABS were investigated (Table 3.1).

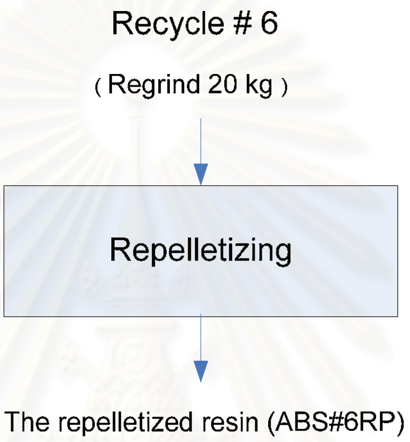


Figure 3.2 Schematic diagram for the preparation of the repelletized resin.

Table 3.1 Preparation of the recycled ABS#6 blended with virgin ABS at various ratios

Sample ratios	Virgin (kg)	ABS#6RP (kg)
Sample Virgin 100%	4.0	0
Sample Virgin 80%	3.2	0.8
Sample Virgin 60%	2.4	1.6
Sample Virgin 40%	1.6	2.4
Sample Virgin 20%	0.8	3.2
Sample Virgin 0%	0	4.0

3.4 Repelletizing

The 6th recycled ABS was repelletizing for injection molding by vented single screw extruder ISHINAKA Model HS-50. A single screw extruder has a screw diameter of 45 mm and L/D ratio is 32:1. The temperature profiles were 190, 200, 210 and 220 °C for feed zone, the compression zone and the metering and die end respectively, as shown in Figure 3.3. The screw speed was held at 25 rpm and extrude materials is repelleted after passing through cooling water at 30 °C.

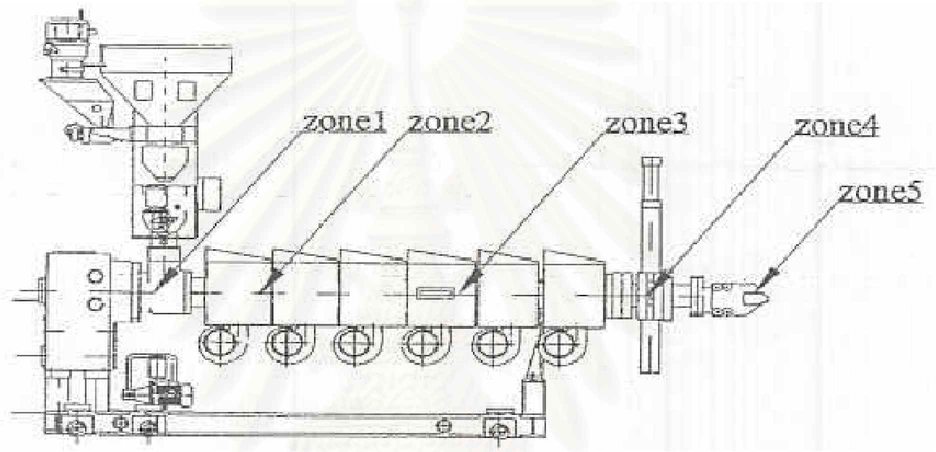


Figure 3.3 Schematic diagram of single screw extruder.

Zone1: Temperature of feed zone = 190 °C
Zone2: Temperature of compression zone = 200 °C
Zone3: Temperature of metering zone = 210 °C
Zone4: Temperature of screen changer = 220 °C
Zone5: Temperature of Die = 220 °C

3.5 Specimen preparation

Test specimens for mechanical testing were prepared by injection molding on a NESEI Model FS80S12 ASE injection molding machine at 300 kg/cm^2 injection pressure, with 3 and 5 seconds of injection and cooling times, respectively, followed by cooling at ambient temperature. The temperature profiles were 190, 200, 210 and 220 °C for the feed zone, the compression zone and the metering and nozzle end, respectively, as shown in Figure 3.4. All the specimens were conditioned according to ASTM D638.Tests were conducted at 25 ± 2 °C. The sample geometries conformed to ASTM D790 for flexural strength and flexural modulus, and ASTM D256 for impact.

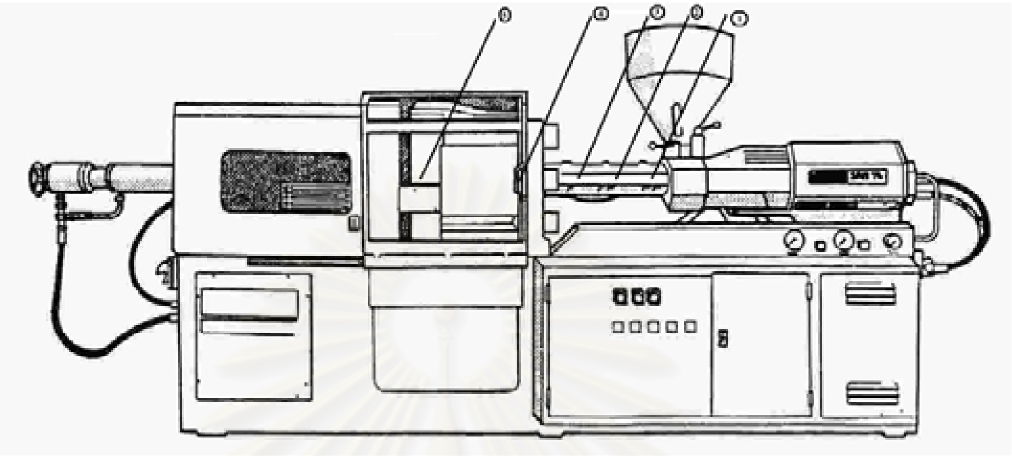


Figure 3.4 Schematic diagram of injection molding machine.

Zone1: Temperature of feed zone = 190 °C
Zone2: Temperature of compression zone = 200 °C
Zone3: Temperature of metering zone = 210 °C
Zone4: Temperature of nozzle = 220 °C
Zone5: Temperature of mould = 25 °C

3.6 Physical properties testing of samples

All mechanical testing was conducted with 7 to 10 specimens and the minimum and maximum values were eliminated for standard deviation calculations. All statistical calculations were performed in a specimen as shown in Figure 3.5.

3.6.1 Tensile strength and elongation testing

The tensile strength and elongation properties were measured according to ASTM D638 using the INSTRON model 4302. The dumb-bell specimen of type I was used, the dimensions of the dumb-bell specimen of type I, the crosshead speed was set constant at 5 mm/min

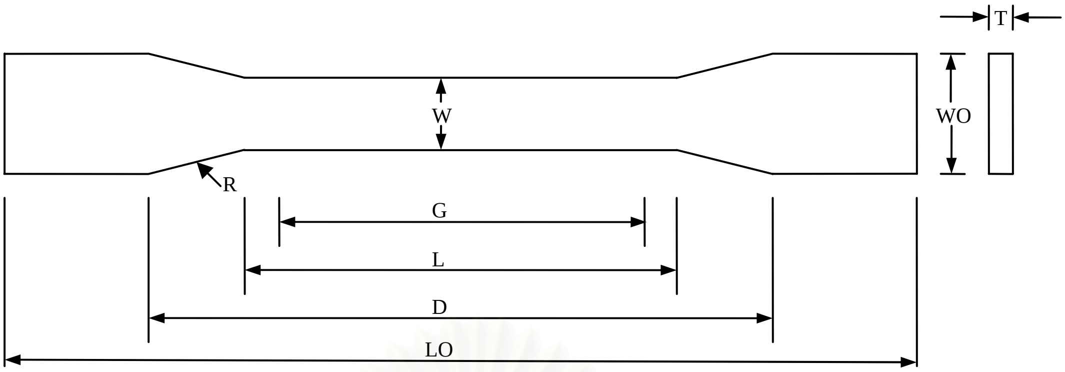


Figure 3.5 The dimensions of dumb-bell specimen of ASTM D638, type I.

W: Width of narrow section	13
L: Length of narrow section	57
WO: Width overall	19
LO: Length overall	215
G: Gauge length	50
D: Distance between grips	100
R: Radius of fillet	76
T: Thickness	3.2

All dimension in millimeters (mm)

3.6.2 Flexural modulus testing

Flexural Modulus testing was performed according to ASTM D790, using the Zwick model 1435.01 as shown in Figure 3.6. The sample was placed on the supports; the crosshead speed was set for constant rate at 2.0 mm/min.

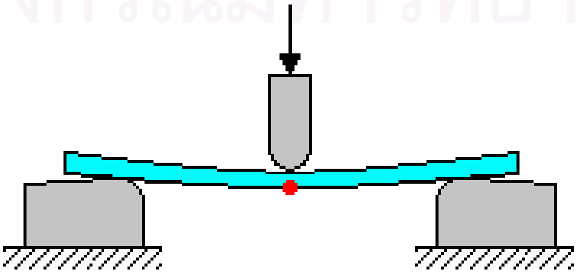


Figure 3.6 Schematic diagram of the flexural modulus testing.

3.6.3 Impact testing

Testing specimens of 64 mm x 12.7 mm x 3.2 mm for the measurement of Izod impact strength were prepared by following ASTM D4101. Impact testing was performed according to ASTM D256 using the Zwick impact tester Model 5102.100/100 as shown in Figure 3.7. The sample was placed on the tester, the pendulum was released to hit the sample with its heat and the energy that caused the sample to fracture was measured.

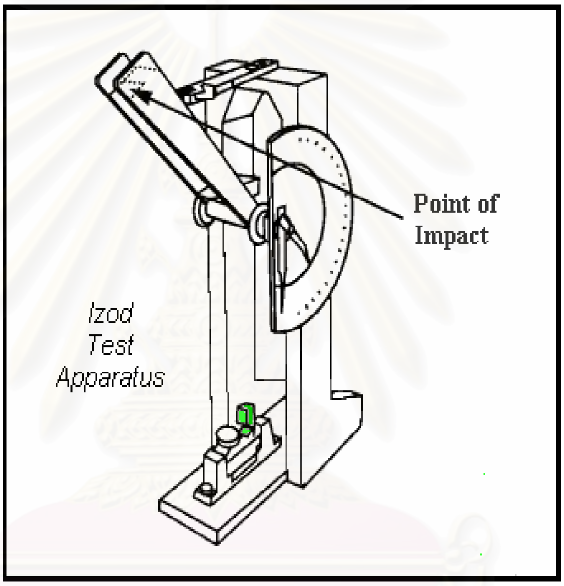


Figure 3.7 Schematic diagram of the impact tester.

3.6.4 Heat distortion testing

Heat distortion testing was performed according to ASTM D648 using the Davenport deflection temperature tester as shown in Figure 3.8. The sample was placed on the metal supports for the specimens which are 100 mm apart, allowing the load to be applied on top of the specimen vertically and midway between the supports and provided with a means of raising the temperature at a uniform rate.

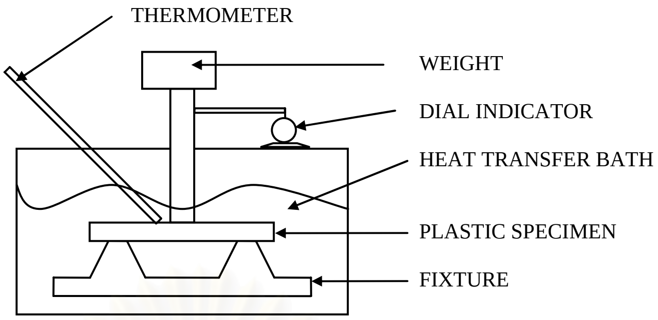


Figure 3.8 Schematic diagram of heat distortion tester.

3.6.5 Melt flow index tester

The melt flow index was measured according to ASTM D1238 as shown in Figure 3.9 using the Yayeness Model 7054P/1. The weight in gram of molten resin through an orifice for 10 min under a weight of 10 kg at a temperature of 220 ^{O}C

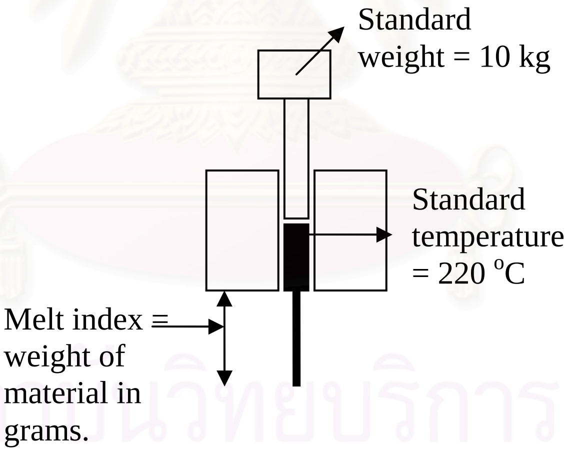


Figure 3.9 Schematic diagram of melt flow index tester.

3.7 Differential scanning calorimeter (DSC)

The melting temperature of the ABS recycled were tested according to ASTM D3417 as shown in Figure 3.10 in which the crystallization and melting behavior were studied by differential scanning calorimeter using the PERKIN ELMER DSC7.

Sample ranging in size from 6 to 10 mg was sealed in an aluminum pan and covered for analysis. A reference standard was used to calibrate the temperature scale and enthalpy of melting. First, the sample was melted by raising the temperature to 150 ^{O}C, kept for 10 min to ensure complete melting and to remove the thermal history. The sample was then cooled to -100 ^{o}C. The melting endothermic after crystallization was recorded by heating the sample directly to 150 ^{o}C at the heating rate 20 ^{o}C/min. The sample cell was then submerged in the liquid nitrogen for the rapid crystallization, thus a DSC scan of the specific energy against the temperature was obtained, and whereas melt temperature was calculated based on the reference temperature is defined 100% crystallization. Finally, the melting endothermic of the quenched sample was obtained with the above procedure.

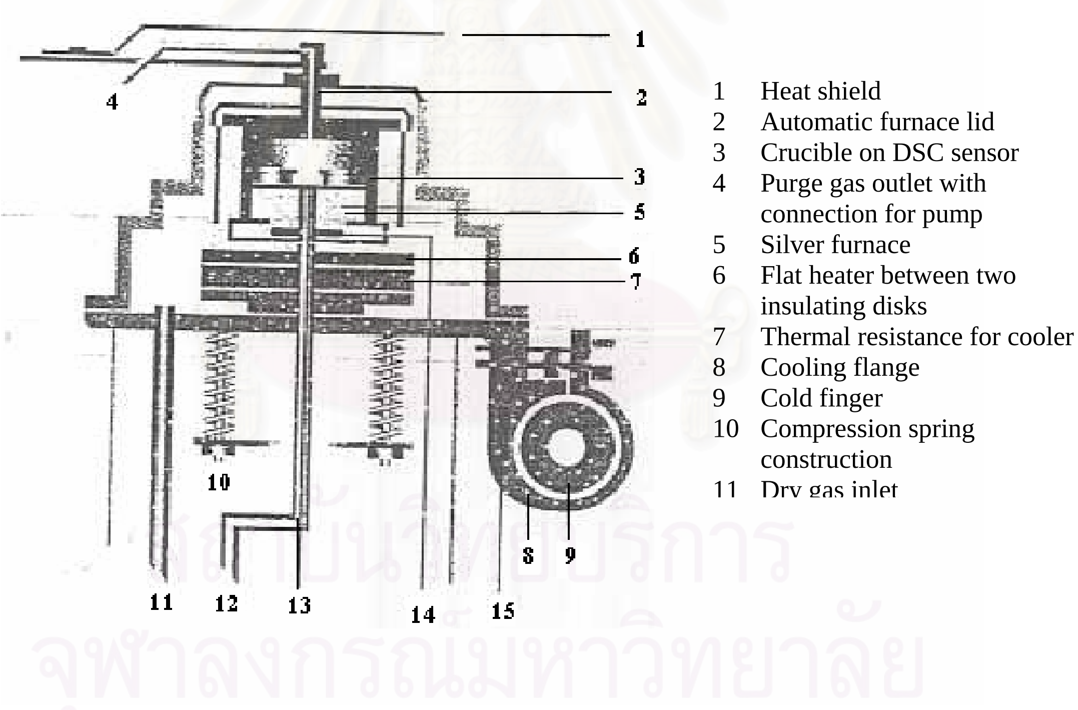


Figure 3.10 Schematic diagram of the DSC.

3.8 Scanning electron microscope (SEM)

SEM was used to observe the morphology photograph for determining the changing of recycled ABS. In scanning electron microscopy, a fine beam of electrons is scanned across the surface of an opaque specimen to which was impacted. secondary electrons, backscattered electrons, or (in the electron microprobe) x-ray photons emitted when the beam hits the specimen are collected to provide a signal used to modulate the intensity of the electrons beam in a television tubes, scanning in synchronism with the microscope beam. Because the latter maintains its small size over large distances relative to the specimen, the resulting images have great depth of field and a remarkable three-dimension appearance. Resolution is currently limited to the order of 100 A^o.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 The physical properties of recycled ABS (1st – 6th generations).

This research was divided into two parts. The first part involved the changing properties of recycled ABS from the virgin to the 6th recycled ABS. This study was focusing on how the properties change in each generation of repeated manufacturing from the virgin ABS to six cycles. The 6th recycled ABS represented the maximum practice of ABS usage in industry. The recycled ABS in each generation was injected to form sample part and then the sample was grinded to the scrap before heat aging at 90 ^{o}C for 72 hours (presented in Fig 3.1). This aging condition was a simulated condition for 1-2 years usage of ABS [2].

In manufacturing by injection molding, in the first part, samples were subjected to heat and shear stress. Shriver [11] explained that during polymer processing, materials experience thermal and mechanical loadings which produced molecular degradation. Molecular degradation would lower the mechanical and rheological properties of the material. Arostegui [13] reported that polymers were subjected to high temperature and shear stress during an extrusion/injection process (commonly used in mechanical recycling), leading to thermal, mechanical, oxidative or combinations of these degradation mechanisms.

The degradation of ABS was known as radical process and the butadiene phase was the most vulnerable sites for degradation [14]. The evolution of butadiene from ABS was found to commence at 340 ^{o}C, styrene at 350^{o}C and acrylonitrile at 400 ^{o}C [12]. Oxidative degradation as a complex of radical chain reaction was proposed to cause polymers mainly to chain scission and crosslinking [15].

However, the first section was investigation on the degradation of recycled ABS from the virgin to the 6th recycled. Rheological behavior, mechanical properties, thermal properties and morphology were analyzed in this experiment.

4.1.1 Melt Flow Index

From Figure 4.1, the MFI was decreasing which meant MFI would decrease following an increasing number of regenerations. The virgin ABS and the 6th recycled ABS showed MFI at 36.1 g/10 and 33.8 g/10 min, respectively.

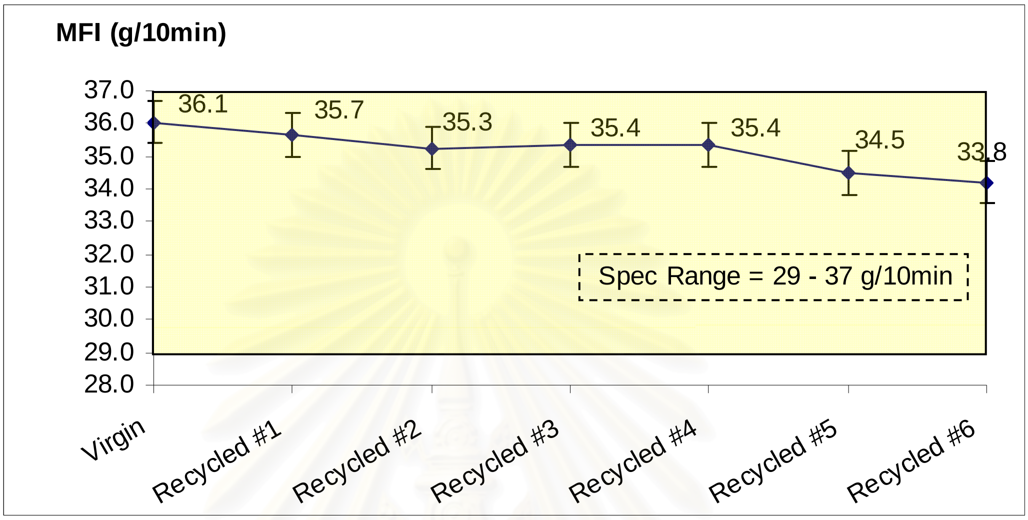


Figure 4.1 Effect of melt flow index of recycled ABS 1st – 6th.

MFI had a tendency to decrease which was explained by the crosslinking of rubber particles. Blom [10] reported that the butadiene phase of the ABS was the most susceptible to oxidative degradation which led to crosslink formation and decreased chain mobility. The combination of two rubber chains from a pre-crosslink would increase the molecular weight. Although many experiments reported that repeating in the extrusion process would increase MFI by reduction of molecular weight, this case was different because this experiment used high flowing grade ABS which had low molecular weight or short polymer chains. Tiganis [8] described that ABS degradation showed a significant increase by using FTIR techniques. It indicated chemical changes in polybutadiene (PB) phase that explained the chain scission and crosslinking. Degradation of the PB phase by crosslinking would also be expected to reduce polymer chain mobility and decrease free volume. Increasing number of regenerations would result in crosslinking, therefore viscosity increased or MFI slightly decreased.

In the manufacturing process the high flowing grade of ABS could be manufactured by the injection process. Although MFI was decreased to about 5% for the 6th recycled ABS, it did not affect injection process ability.

4.1.2 Izod notched impact strength

From Figure 4.2, it was found that NI was decreasing which meant that NI would decrease following an increasing number of regenerations. The virgin ABS and the 6th recycled ABS showed NI at 23.4 kg-cm/cm and 19.5 kg-cm/cm or a 16.6% decrease, respectively.

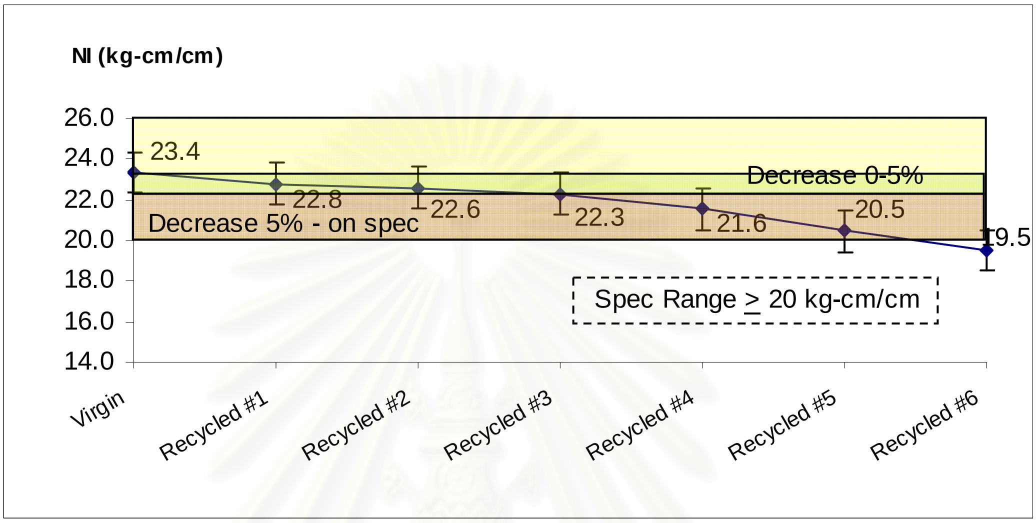


Figure 4.2 Effect of Izod notch impact strength of recycled 1st – 6th.

The decreased of NI was in line with other which was reported in the literatures. ABS with the highest butadiene content exhibited the highest rate of yellowing and the greatest loss of impact strength [15]. The result indicated that NI in recycled ABS was dependent on the number of recycling. It could be explained that the rubber particles were demolished, and as a consequence the ABS specimen was shown to be brittle and lost flexibility. The impact resistance of a plastic was decreased by the reduction of small quantities of the rubber particle in a plastic [16]. Oxidation of polybutadiene in ABS under heated and compressed conditions resulted in embrittlement of the rubber owing to cross-linking. The embrittlement of the elastomer in ABS would reduce impact resistance [4]. Failure under impact depended on the condition of the surface layer in ABS. Crosslinking and degradation products such as polymer peroxides increased in Young’s modulus and reducing contribution of PB phase [8].

However, the data could be separated into two groups. Group 1 (high impact resistance) showed reduction at about 0 to 5 percent (22.23 - 23.4 kg-cm/cm) and indicated that virgin and recycle#1 should be used. The plastic parts of this group were electrical parts (part of an air-conditioner, a humidifier and a microwave) and automobile parts (interior parts, a console accessories and a windscreen).

Group 2 (low impact resistance) showed 5 percent reduction from specification (20 - 22.23 kg-cm/cm) and it indicated that recycle#2, recycle#3, and recycle#4 could be used. The plastic parts of this group were several household products such as bowls, plates, knobs, screens, clocks and toys.

4.1.3 Rockwell Hardness

The experiments of hardness indicated that HR was significantly unchanged through an increasing number of regenerations, as shown in Figure 4.3. The virgin ABS and the 6th recycled ABS showed HR at 111.5 R-scale and 111.0 R-scale, respectively.

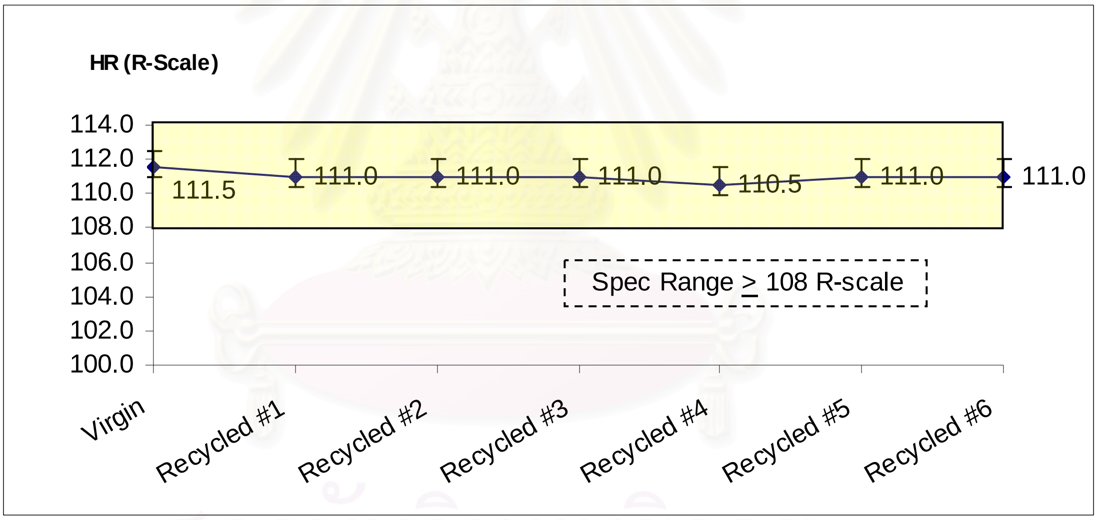


Figure 4.3 Effect of Rockwell hardness of recycled 1st – 6th.

The hardness was measured from the surface specimen. This analysis indicated that quantity of recycled ABS had no effect with the hardness of surface. HR direction should not associate with FS but Piriyaphokanont [17] reported that migration of rubber particle phase would increase HR and FS at approximate 5% and 15% respectively. This suggestion implied that the HR which indicated stiffness was less sensitive than FS.

4.1.4 Tensile strength at break

It was found that TS was relatively unchanged through an increasing number of generations, as shown in Figure 4.4. The virgin ABS and the 6th recycled ABS showed TS at 478.5 kg/cm^2 and 470.5 kg/cm^2, respectively.

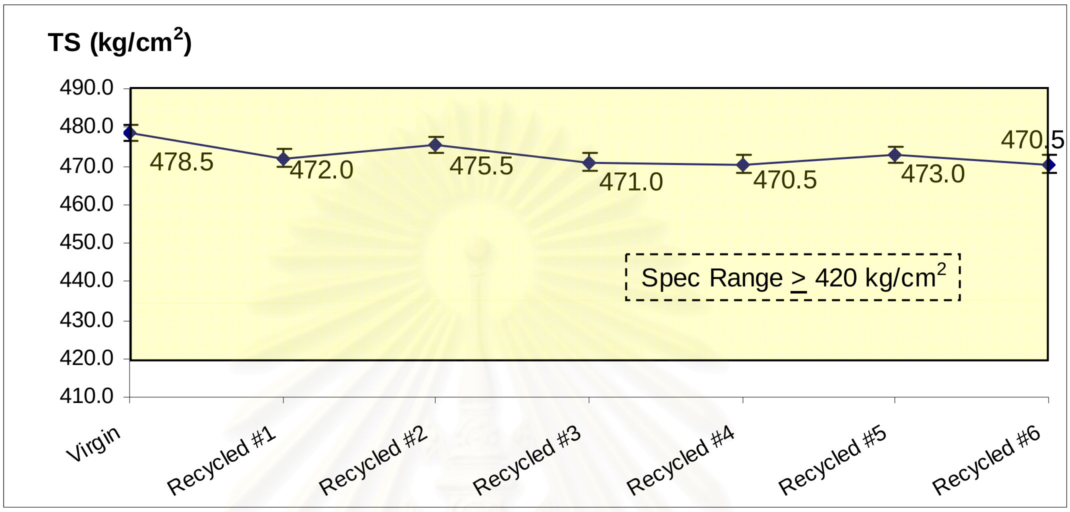


Figure 4.4 Effect of tensile strength of recycled 1st – 6th.

The mechanical properties of ABS after reprocessing had been studies by tensile testing. These data suggested that ductility was constant after recycling. Bastida [7] reported that the reduction in ductility was also a usual consequence of reprocessing. The increasing of the molecular weight of SAN which was the narrow molecular weight distribution caused increases in TS.

Tiganis [8] explained that the property of tensile energy at break of aging ABS between 90 and 120 ^{o}C significantly deteriorated as the temperature and time of aging increased. The toughness experiment showed that TS largely oscillate so the changes in properties would clearly lead to difficulties in products design based on TS**.** However, TS values were in the range of quality control which was a suitable value for manufacturing in industry.

4.1.5 Elongation at break

From Figure 4.5, it was found that elongation at break decreased from virgin to recycled#1. The EL was almost unchanged from recycled#2 to recycled#6. The virgin ABS showed and the 6th recycled ABS show EL at 25 % and 9 %, respectively.

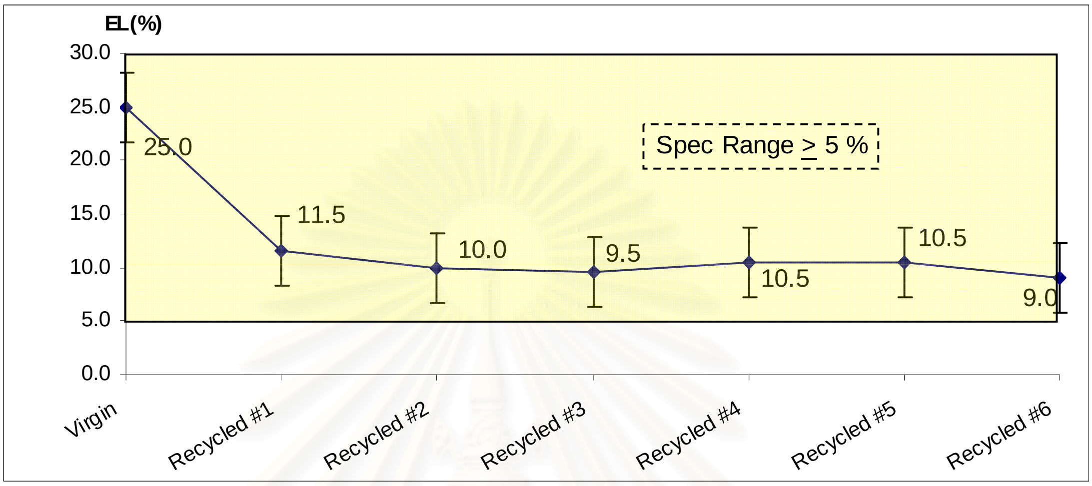


Figure 4.5 Effect of elongation at break of recycled 1st – 6th.

The elongation decreased through an increasing number of regenerations. In the injection series, the EL of recycled ABS from the virgin to 1st recycled ABS rapidly decreased although the EL of recycled ABS from the 2nd to the 6th recycled ABS was almost unchanged. One possible explanation to the decrease in elongation was the degradation of the rubber phase during the injection processing which effects directly on EL. Boldizar [2] reported the change in elongation of ABS recycling and such changes in properties would clearly lead to difficulties of products design based on EL because the difference between two adjacent values was 9% to 12% after first extrusion and combined series. This research demonstrated that 50% reduction after the first injection was observed. Elongation at break for elastomer was of the order of several hundred percent and was indicated by the dot at the end of the stress-strain curve. The crystallizing elastomer had much higher tensile than non-crystallizing elastomer [16]. This assumption was true in practice because ABS was amorphous polymer, which composed of crystallization and non-crystallization parts, resulting in the oscillatory values of EL and TS properties. In conclusion, EL had no effect on quality of product in the injection application and EL values showed in this experiment was still within specification.

4.1.6 Flexural Strength and Flexural Modulus

It was found that FS was increasing following an increasing number of regenerations. The virgin ABS and the 6th recycled ABS showed FS at 616 (x10^4kg/cm^2) and 633.5 (x10^4kg/cm^2), respectively.

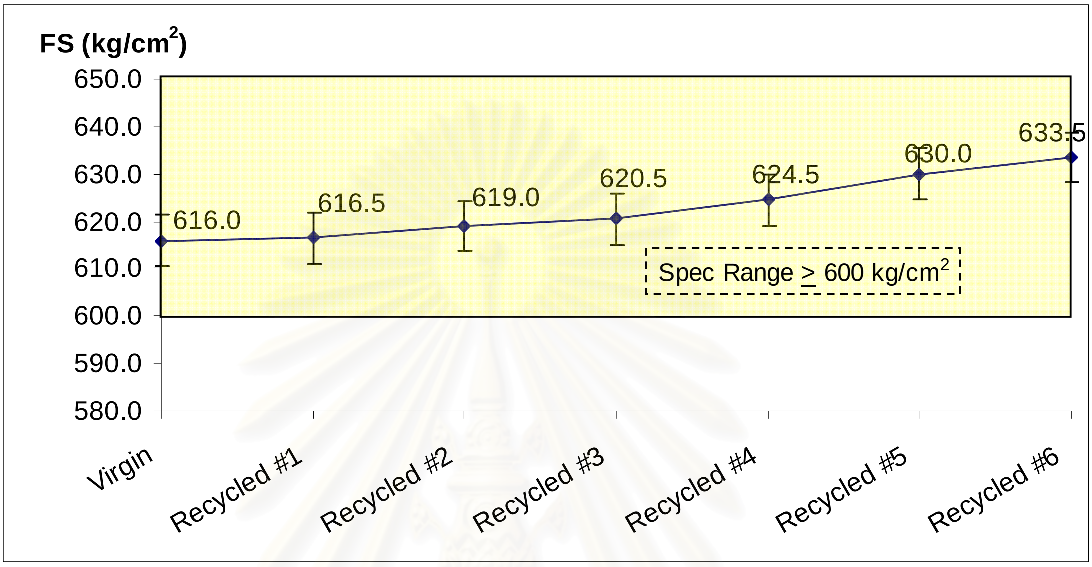


Figure 4.6 Effect of flexural strength of recycled 1st – 6th.

The increase in flexural strength and flexural modulus after recycling was associated with crosslinking and reductions in free volume in the polymer matrix [8]. One explanation was that on a macro level of physical aging process stiffness of specimen was increased. The crosslinking should be called “physical crosslinking” rather than chemical crosslinking. This crosslinking could be defined as non-covalent bond. Thermal stability was the most important physical crosslinking that block co-polymer formation resulted in increasing of result the stiffness [16].

This analysis was probably due to both rubber particle size changing and the crosslink level in the rubber phase. As it would be expected when rubber content was lost, the FS would be increased. The FS was increased to about 3% for 6th recycled ABS but increasing of FS had no effect on quality of product.

Figures 4.7 shows that FM from this experiment tended to increase following an increasing number of generations. The virgin ABS and the 6th recycled ABS showed FM at 2.095 (x10^4 kg/cm^2) and 2.13 (x10^4 kg/cm^2), respectively.

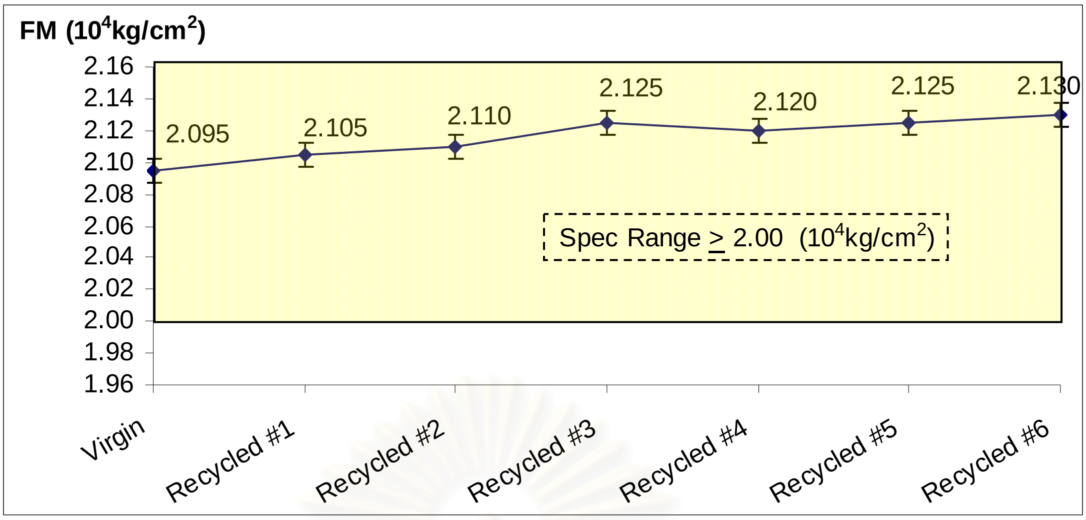


Figure 4.7 Effect of flexural modulus of recycled 1st – 6th.

The increase of FM was in agreement with those reported by Tiganis [8] and Munteanu [18] experiment. In conclusion, both FM and FS tended to increase in the same direction but they were in specification of manufacturing process.

4.1.7 Heat distortion temperature

In Fig 4.8, it was found that HDT was basically unchanged through an increasing number of regenerations. The virgin ABS and the 6th recycled ABS showed HDT at 84.6 °C and 84.7 °C, respectively.

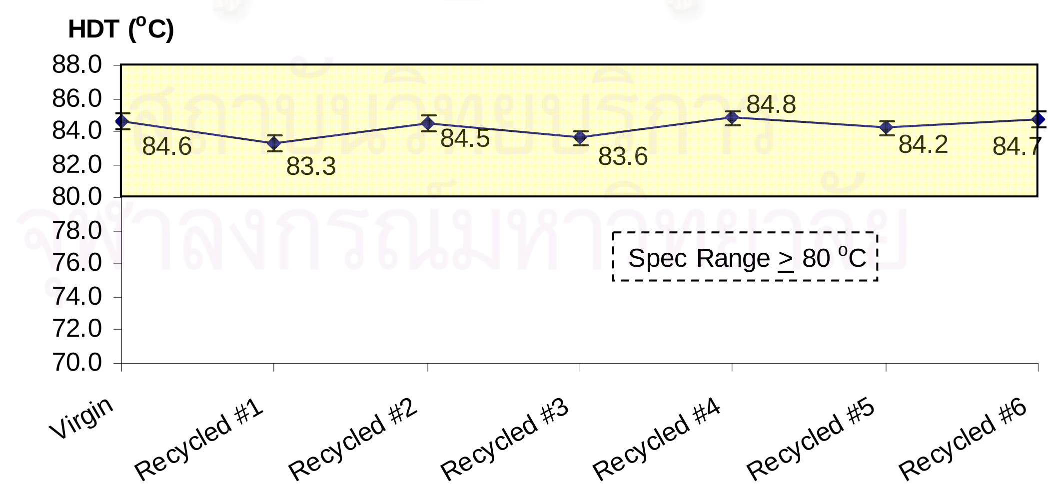
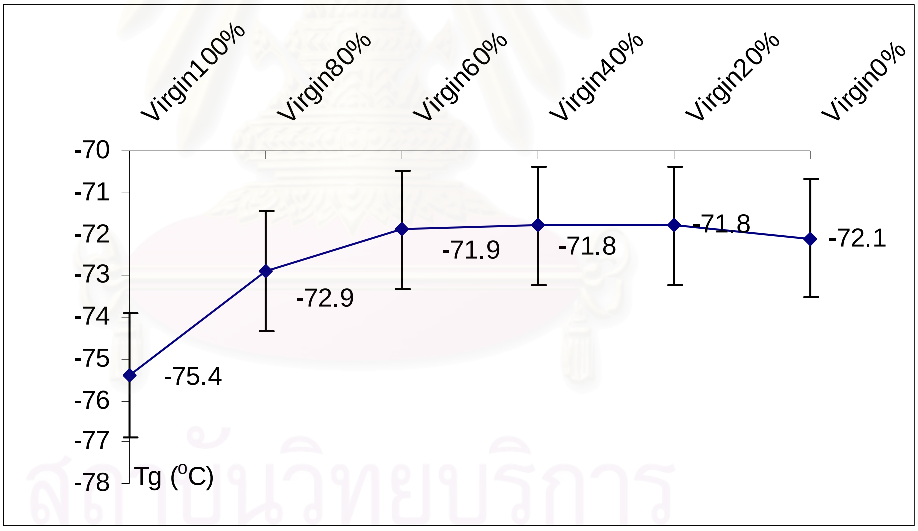


Figure 4.8 Effect of heat distortion temperature of recycled 1st – 6th.

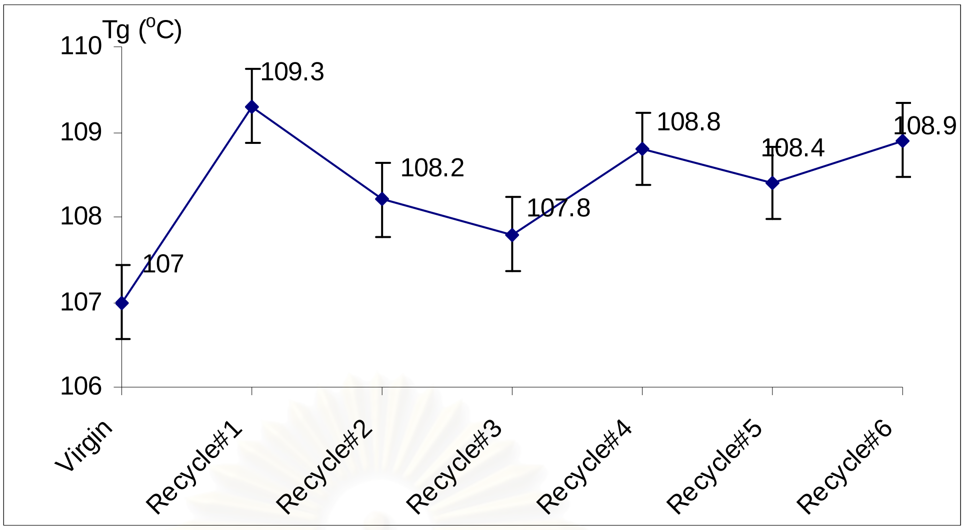
The HDT was measured from the surface specimen and tended to be constant which was similar to the HR results. Recycled ABS had no effect on the thermal property of HDT. HDT values associated with the chemical structure. If recycled ABS did not change the chemical structure, HDT would not be changed.

4.1.8 Differential Scanning Calorimeter

DSC curves of the ABS resin showed the T_g at two positions. The first position which was glass transition butadiene phase which was apparent about -75.4 to -71.8 °C (as shown in Fig. 4.9 (a)) and the second position which was of styrene-acrylonitrile phase T_g about 107 to 109.3 °C (as shown in Fig. 4.9 (b)). It was found that T_g increases follow an increasing number of generations which T_g of virgin ABS and the 6th recycled ABS in butadiene phase showed T_g at -75.4 °C and -72.1 °C, respectively and T_g of virgin ABS and the 6th recycled ABS in SAN phase showed T_g at 107 and 108.9 °C, respectively.



(a)



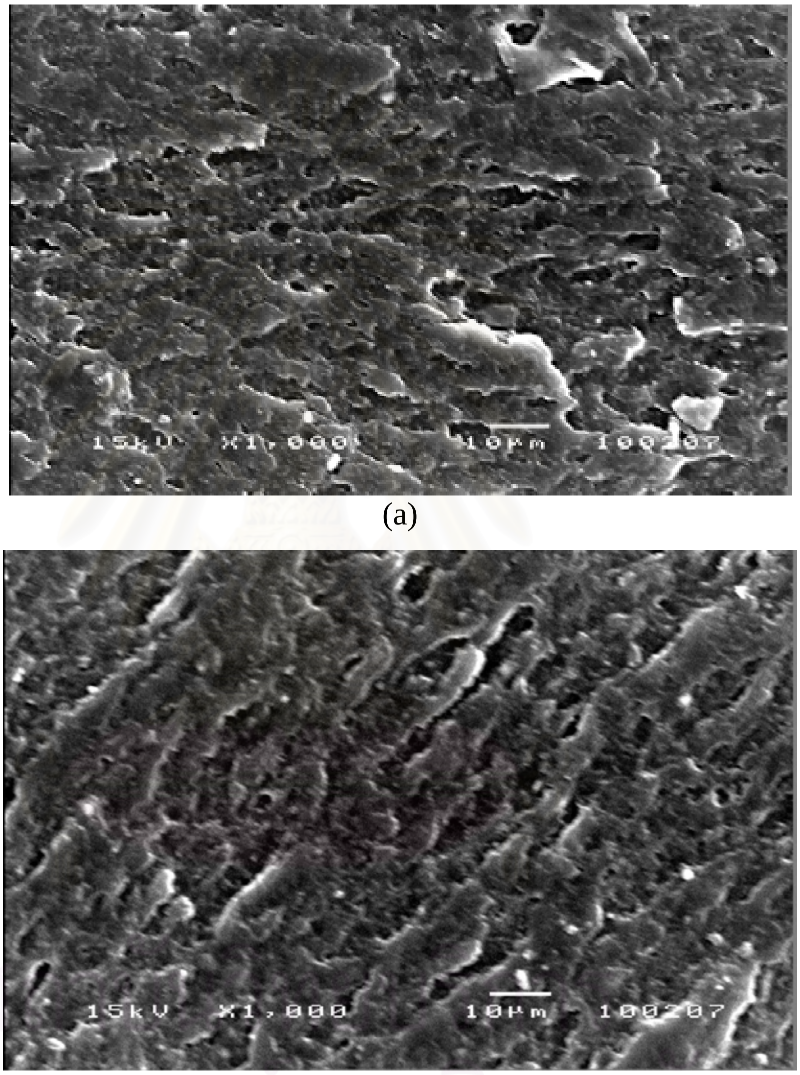
(b)

Figure 4.9 Effect of Tg of recycled 1st – 6th (a) butadiene phase (b) styrene-acrylonitrile phase.

Blom [10] explained that increasing in the glass transition temperature (T_g) was expected for degraded samples. This experiment was significant that T_g of virgin ABS was lower than T_g of recycled ABS#6. The thermodynamic theory explained that it successfully predicted the variation of T_g with molecular weight and crosslinking. Decrease in free volume with increasing molecular weight caused the increasing T_g in both butadiene and styrene-acrylonitrile phase [16]. Munteanu [18] explained that FTIR, DSC and DMTA experiments showed chain scission and crosslinking reactions. Thus, the increasing of T_g should be originated from the crosslinking in the butadiene phase.

4.1.9 Scanning electron microscope

SEM was used to investigate the state of dispersion of polymer degradation between virgin ABS and the 6th recycled ABS in this work (presented in Figure 4.10)



(a)

(b)

Figure 4.10 Scanning electron micrographs for (a) virgin (b) the 6th recycled.

SEM studies revealed no significant changes in size, shape or distribution of the rubber particles in the 6th recycled ABS compared with those of virgin ABS. Although some indications of agglomeration of the polybutadiene particles in the sixth recycled and virgin ABS were observed, both of them have no change in characteristic. SEM could not indicate this difference from appearance.

Although both physical aging and thermo-oxidative degradation of the SAN phase could occur their overall deterioration of ABS mechanical properties were comparatively insignificant compare to the effects of thermo-oxidative degradation of the PB phase. Arostegui [13] explained that the new adsorption band was in agreement with the fact that the degradation of butadiene phase took place especially in unsaturated bonds, leading to a new product with carbonyl group. Therefore, the degradation of ABS upon these experimental conditions occurred in butadiene phase, and not in SAN copolymer.

4.2 The physical properties of recycled ABS#6 blended with virgin ABS.

The second part investigated the changing properties of the recycled ABS. The maximum recycled ABS was prepared from the 6th recycled ABS which represented the maximum practice of ABS usage in industry. The repelletized resin called ABS#6RP was blended with virgin ABS at ratios 0, 20, 40, 60, 80 and 100% by weight of virgin material.

The additional of the virgin material to the recycled material could improve its physical, mechanical, and rheological properties. The rheological and mechanical test for various ratios would lead to guidelines for the minimum amount of virgin material needed to obtain target performance levels. With the completion of this study, engineers could specify a target part performance level, rather than specifying specific virgin/recycle ratios [11].

4.2.1 Melt flow index

From Figure 4.11, it was found that MFI decreased from virgin 100% into virgin 0% (repelletized100%). The virgin 100% ABS and the virgin 0% ABS showed MFI at 36.4 g/10 min and 34.3 g/10 min, respectively.

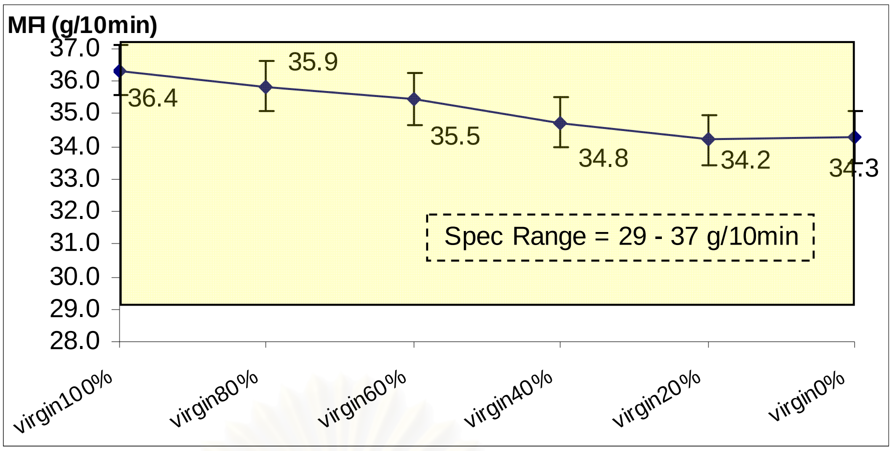


Figure 4.11 Effect of MFI of the virgin/repelletized.

MFI decreases when the quantity of ABS#6RP was increased. It was found out that the lowest and highest of MFI value were between 34.3 and 36.4 g/10min respectively. These values were in the range of quality control (29 - 37 g/10min) in manufacturing process.

4.2.2 Izod notched impact strength

It was found that NI decreased from virgin 100% to virgin 0% (repelletized100%) following an increasing quantity of repelletized resins, as shown in Figure 4.12. The virgin 100% ABS and the virgin 0% ABS showed NI at 23.4 kg-cm/cm and 19.4 kg-cm/cm, respectively.

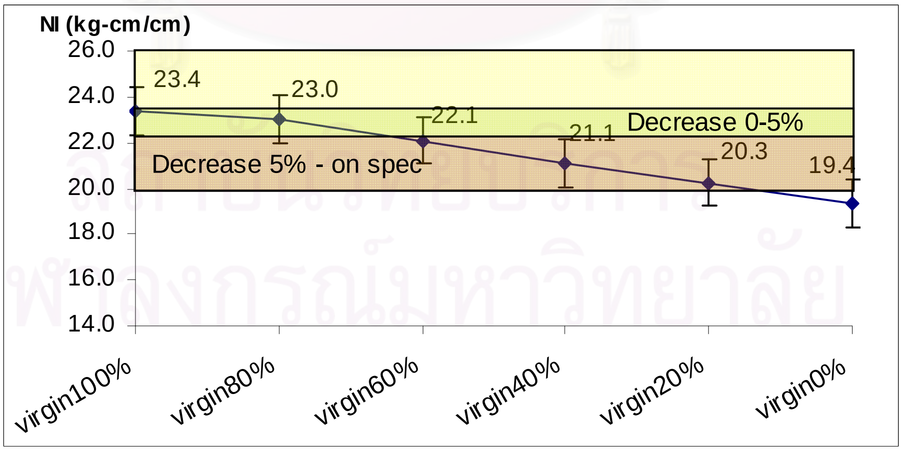


Figure 4.12 Effect of NI of the virgin/repelletized.

Shriver [9] indicated that impact strength increased with increasing virgin material percentage. It was found that NI had a tendency to decrease significantly.

Reduction of NI was caused from quantity of the repelletized resins which compose of the degradable rubber. This experiment could be separated into two groups after blending ABS#6RP as follow;

Group 1 (high impact resistance) showed reduction from 0 to 5 percent (23.4 - 22.23 kg-cm/cm) and indicated that ABS#6RP should not be used more than 20 percent. The plastic parts of this group were such as electrical parts (part of an air-conditioner, a humidifier and a microwave) and automotive parts (interior parts, a console accessories and a windscreen).

Group 2 (low impact resistance) showed 5 percent reduction from specification (22.23 – 20 kg-cm/cm) and indicated that quantity of ABS#6RP could be used more than 60% .The plastic parts of this group were such as bowls, plates, knobs, screens, clocks and toys.

4.2.3 Rockwell hardness

From Figure 4.13, it was found that HR was significantly unchanged although the quantity of repelletized resins was increased. The virgin 100% ABS and the virgin 0% ABS showed HR at 111.5 R-scale and 111 R-scale, respectively.

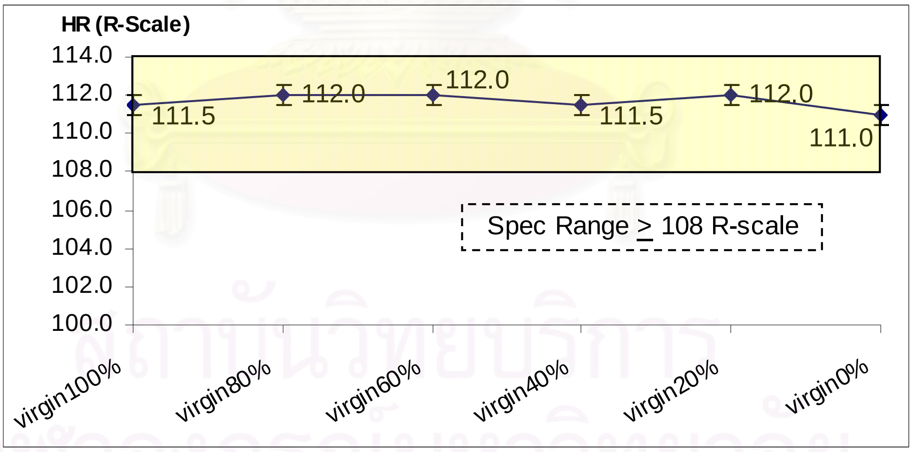


Figure 4.13 Effect of HR of the virgin/repelletized.

Product Control Department of IRPC specified HR at higher than 108 R-scale. HR was measured from the surface specimen and tended to be constant which could be concluded that ABS#6RP at various ratios had no effect on the surface hardness.

4.2.4 Tensile strength

From Figure 4.14, it was found that TS was relatively unchanged from the virgin 100% to virgin 0% (repelletized100) following an increasing quantity of repelletized resins. The virgin 100% ABS and the virgin 0% ABS showed at 476 kg/cm^2 and 471 kg/cm^2, respectively.

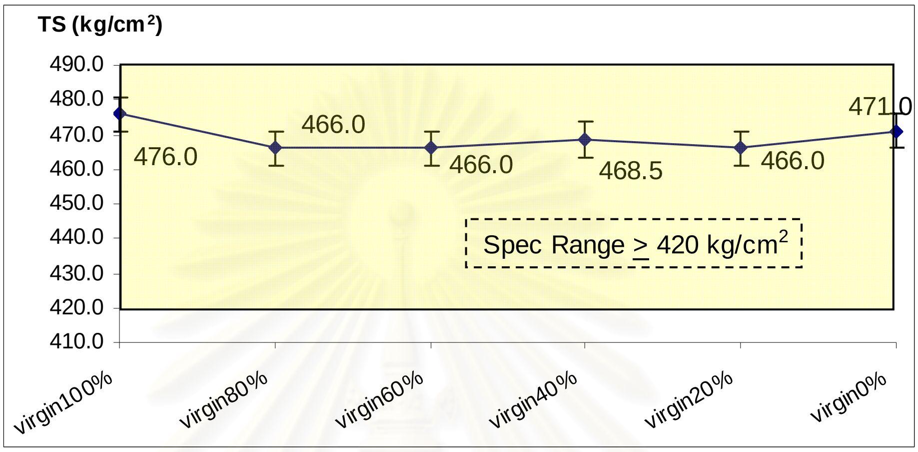


Figure 4.14 Effect of TS of the virgin/repelletized.

In the literatures, the large oscillating change in TS by using recycled ABS will lead to difficulties in products design based on TS**.** However TS in this experiment was almost unchanged. The finish goods which were designed based on TS could be using the scraped or recycled plastics because TS was almost unchanged.

Product Control Department in IRPC specified the minimum TS at 420 kg/cm^2 for this grade that did not define a specification on narrow range because most parts which were produced from this grade do not required high TS.

4.2.5 Elongation at break

EL from this experiment is decreased from virgin 100% ABS to virgin 0% ABS at 22 % and 9 %, respectively.

The elongation decreased following an increasing quantity of repelletized resins, as shown in Fig 4.15. In the injection series, the virgin 100% to the virgin 60% ABS decreased rapidly but the virgin 60% to virgin 0% ABS remained fairly unchanged.

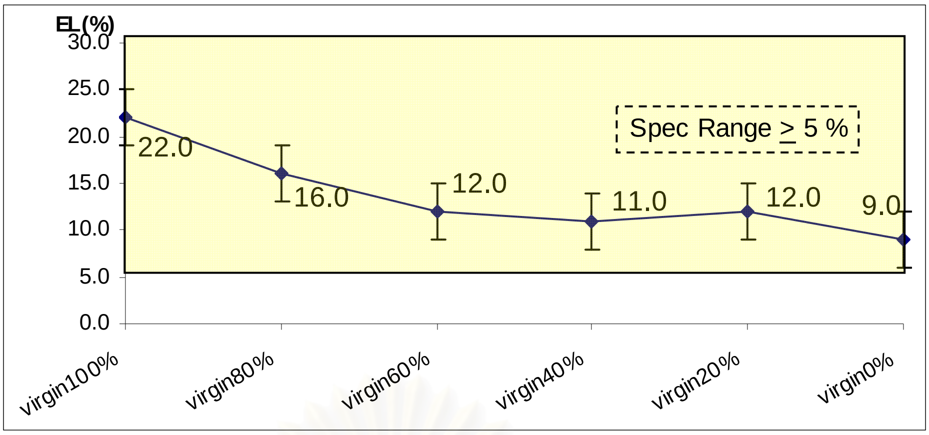


Figure 4.15 Effect of EL of the virgin/repelletized.

EL must be investigated for film and vacuum applications but reduction of EL in injection application was not critical. Product Control Department of IRPC specified EL at higher than 5%. All of EL values were higher than specification

4.2.6 Flexural strength and flexural modulus

From Figure 4.16, it was found that FS was increased from virgin 100% to virgin 0% (repelletized 100%) following an increasing quantity of repelletized resins. The virgin 100% ABS and the virgin 0% ABS showed FS at 618 kg/cm^2 and 635.5 kg/cm^2, respectively.

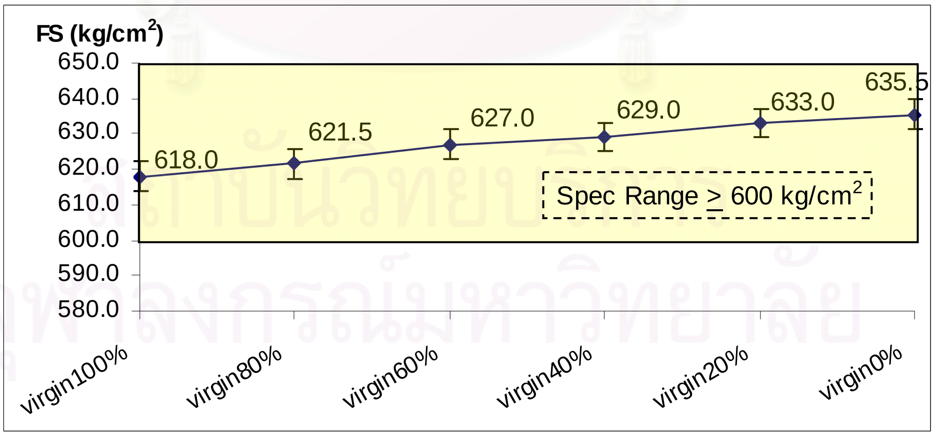


Figure 4.16 Effect of FS of the virgin/repelletized.

From the experiment, it was proposed that increase in flexural strength and flexural modulus after recycling was associated with crosslinking and reductions in free volume in the polymer matrix. Product Control Department in IRPC specified FS at higher than 600 kg/cm^2. All of FS values were higher than specification.

FM from this experiment had a tendency to increase in the same direction of FS, as shown in Figure 4.17. The virgin 100% ABS and the virgin 0% ABS showed FM at 2.10 (x10^{4}kg/cm^2) and 2.14 (x10^{4}kg/cm^2), respectively.

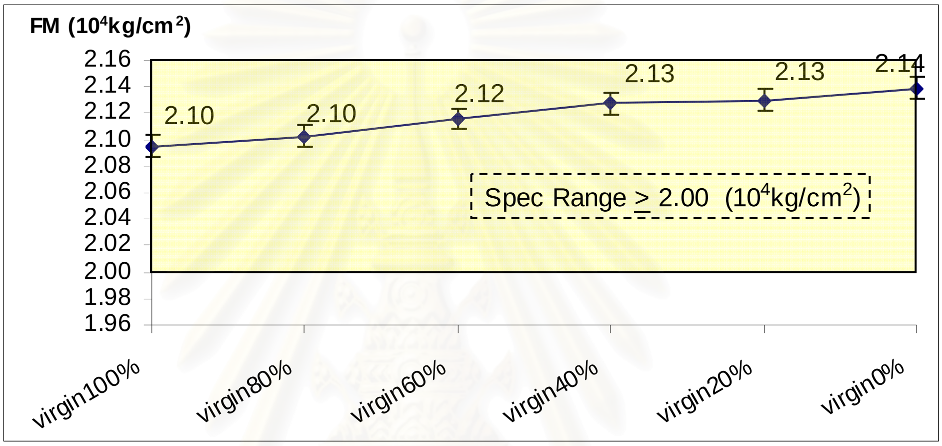


Figure 4.17 Effect of FM of the virgin/repelletized**.**

Product Control Department of IRPC specified FM at higher than 2.00 (x10^{4}kg/cm^2). FM increased by the similar reasons of FS. This analysis was probably due to both rubber particle size and the crosslink level in the rubber phase.

4.2.7 Heat distortion temperature

From Figure 4.18, it was found that HDT was almost unchanged through an increasing quantity of repelletized resins. The virgin 100% ABS and the virgin 0% ABS showed HDT at 84.6 ^{o}C and 84.9 ^{o}C, respectively.

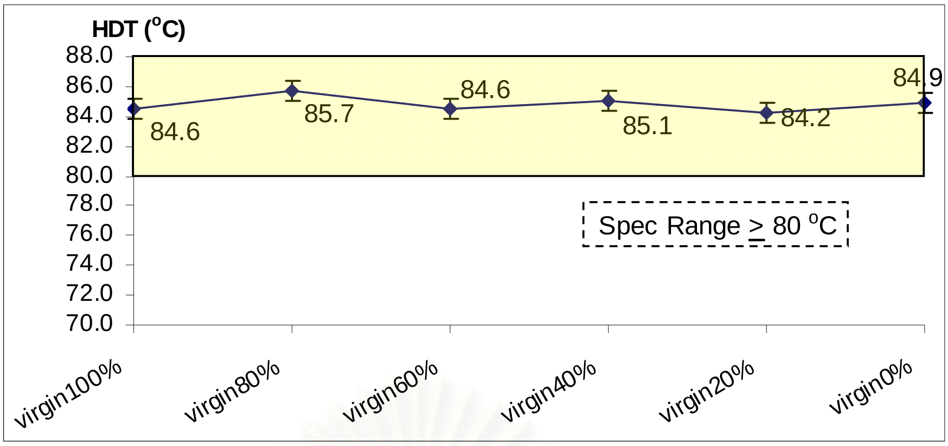


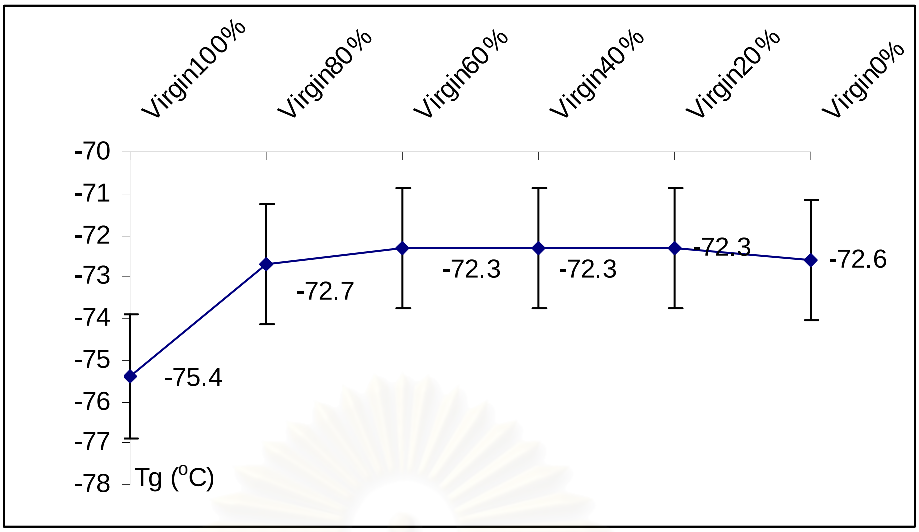
Figure 4.18 Effect of HDT of the virgin/repelletized**.**

Product Control Department of IRPC specified HDT at higher than 80 ^{o}C. HDT was found to be unchanged. This analysis indicated that rubber particle size and the crosslink level in the rubber phase had no effect with chemical structure. Chemical structure was unchanged so HDT was also unchanged. A part that was produced from ABS#6RP was on specification and has no effect on quality of product.

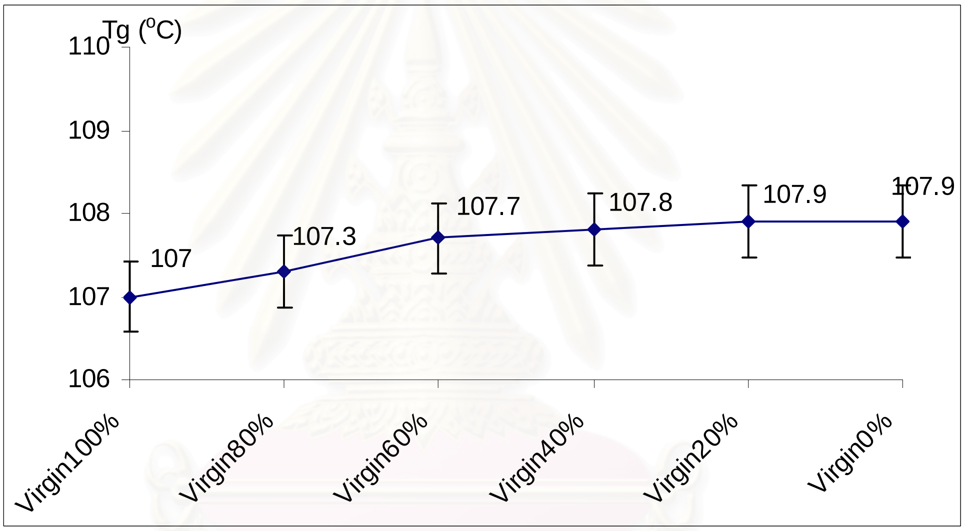
Moreover, the physical properties tended to be in the proportion of the plastic use. If the quantity of repelletized resin was used more than the virgin resin, the properties tended to be similar to those of the repelletized resin but if the virgin resin was used more than the repelletized resin, the properties tended to be similar to those of the virgin resin.

4.2.8 Differential scanning calorimeter

From DSC reports, the T_g at two positions were shown at about -75.4 to -72.3 ^{o}C (Fig. 4.19 (a)) and about 107 to 107.9 ^{o}C (Fig. 4.9 (b)). They belonged to T_g of the butadiene phase and T_g of the SAN phase respectively. It was found that T_g increased when the amount of the repelletized 6th recycled ABS was increased.



(a)

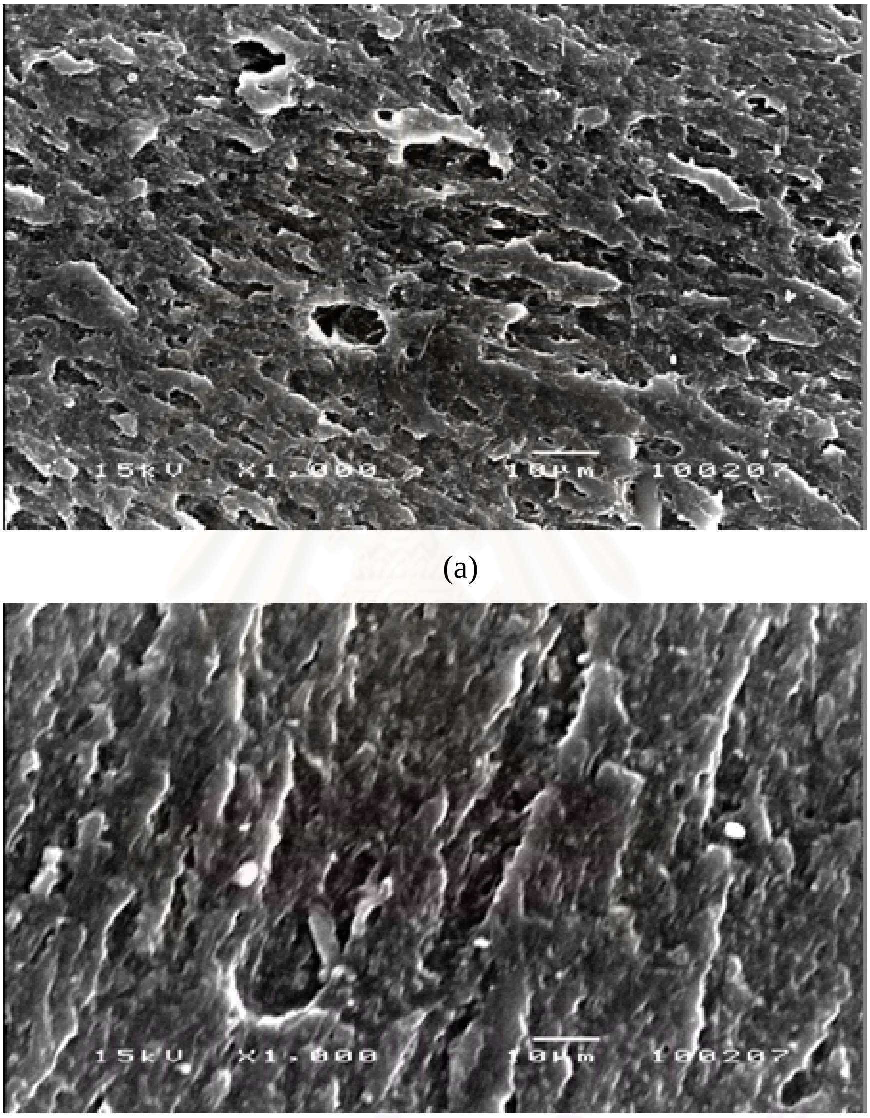


(b)

Figure 4.19 Effect of T_g of virgin/repelletized (a) butadiene phase (b) styrene-acrylonitrile phase.

4.2.9 Scanning electron microscope

SEM was used to investigate the state of dispersion of polymer degradation between virgin 100% and virgin 0% recycled ABS in this work (presented in Figure 4.20)



(a)

(b)

Figure 4.20 Scanning electron micrographs for (a) virgin100% (b) virgin0%.

SEM investigation revealed no significant changes in size. Nevertheless some indications of agglomeration of the polybutadiene particles in the virgin 0% and virgin 100% ABS were indicated that it did not illustrate difference between one and another.

CHAPTER V

CONCLUSION AND FUTURE DIRECTION

5.1 Conclusion

The physical properties of the recycled ABS were investigated. The experiment was separated into two parts. Firstly, the effects from the virgin resin to the sixth recycled were studied. Secondly, the blending between virgin and repelletized of the 6th recycled ABS at various ratios was studied. The experimental results were concluded as the following:

Part one: The physical properties of recycled ABS from the virgin to the sixth recycled ABS were shown below.

- Melt flow index slightly increased. Increase did not affect to quality of manufacturing and product.
- Izod notched impact strength clearly decreased. Decrease directly affected to quality of product because of brittleness but did not affect to quality of manufacturing.
- Rockwell hardness was almost unchanged.
- Tensile strength was almost unchanged.
- Elongation at break slightly decreased Decrease did not affect to quality of manufacturing and product.
- Flexural strength and modulus increased. Increase directly affected to quality of product because of stiffness but did not affect to quality of manufacturing.
- Heat distortion temperature was almost unchanged.
- Differential scanning calorimeter suggested that T_g in the butadiene and styrene-acrylonitrile phase increased. Increase did not affect to quality of manufacturing and product.
- Scanning electron microscope did not show any significant difference.

In the first part, MFI, HR, TS, EL, FS, FM and HDT were still in specification. It could be concluded that these properties give no problem in using recycled ABS in industry. NI was significant and it was out of specification. NI was the important factor which should be considered in using recycled ABS. (presented in Table 5.1)

Table 5.1 Conclusion of physical properties of recycled ABS from the virgin to the sixth recycled ABS

	MFI	NI	HR	TS	EL	FS	FM	HDT
Virgin	/	/	/	/	/	/	/	/
Recycle#1	/	/	/	/	/	/	/	/
Recycle#2	/	s	/	/	/	/	/	/
Recycle#3	/	s	/	/	/	/	/	/
Recycle#4	/	s	/	/	/	/	/	/
Recycle#5	/	x	/	/	/	/	/	/
Recycle#6	/	x	/	/	/	/	/	/

Note / : This mark is acceptable.
x : This mark is unacceptable.
s : This mark is selected for suitable applications.

NI was the property that should be selected for suitable application in manufacturing products.

- Virgin and recycled ABS#1 could be used in the high value product such as electrical parts and automotive parts which have brand name of goods and strictly quality controlled.
- Recycled ABS#2, recycled ABS#3 and recycled ABS#4 could be used in the several kinds of products such as house-hold products, office equipments and toy parts.
- Recycled ABS#5 and recycled ABS#6 could not be used because their qualities were out of specification.

Part two: The physical properties of blending recycled ABS with virgin ABS.

- Melt flow index slightly increased. Increase did not affect to quality of manufacturing and product.
- Izod notched impact strength clearly decreased. Decrease directly affected to quality of product because of brittleness but did not affect to quality of manufacturing.
- Rockwell hardness was almost unchanged.
- Tensile strength was almost unchanged.
- Elongation at break slightly decreased. Decrease did not affect to quality of manufacturing and product.
- Flexural strength and modulus increased. Increase directly affected to quality of product because of stiffness but did not affect to quality of manufacturing.
- Heat distortion temperature was almost unchanged.
- Differential scanning calorimeter suggested that T_g in the butadiene and styrene-acrylonitrile phase increased. Increase did not affect to quality of manufacturing and product.
- Scanning electron microscope did not show any significant difference.

In the second part, MFI, HR, TS, EL, FS, FM and HDT were still in specification. It could be concluded that these properties give no problem in using recycled ABS in industry. NI was significant and it was out of specification. (presented in Table 5.2)

Table 5.2 Conclusion of physical properties of blending recycled ABS from virgin100% to virgin 0%

	MFI	NI	HR	TS	EL	FS	FM	HDT
Virgin100% (Repelletized 0%)	/	/	/	/	/	/	/	/
Virgin80% (Repelletized 20%)	/	/	/	/	/	/	/	/
Virgin60% (Repelletized 40%)	/	s	/	/	/	/	/	/
Virgin40% (Repelletized 60%)	/	s	/	/	/	/	/	/
Virgin20% (Repelletized 80%)	/	x	/	/	/	/	/	/
Virgin0% (Repelletized 100%)	/	x	/	/	/	/	/	/

Note / : This mark is acceptable.
x : This mark is unacceptable.
s : This mark is selected for suitable applications.

- Virgin100% and virgin80% could be used in the high value product such as electrical parts and automobile parts which have brand name of goods and strictly quality controlled.
- Virgin60% and virgin40% could be used in several kinds of products such as house-hold products, office equipments and toy parts.
- Virgin20% and virgin0% could not be used because their qualities were out of specification.

From this research, it was found that ABS could be recycled for four times without causing unacceptable properties. The only property that needed to be selected for certain application was NI because NI was deteriorated after the second recycled ABS. The sixth recycled ABS could not be used. However, blending the sixth recycled ABS up to 40% with virgin ABS gave acceptable materials for product manufacturing. Thus, the life cycle of ABS was further extended.

5.2 Future Direction

Suggestions for future works are

- To characterize the crosslinking in the degradation of rubber particle.
- To study the additives to improve the properties of recycled ABS such as impact modifiers, reinforcement and fillers.

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APPENDICES

APPENDIX A

Table A-1 Specification of GA300/ABS Resin

IRPC PUBLIC COMPANY LIMITED

14thFloor, SunTowerB,125 Vibhavadi Rangsit Road, Kwang Chompol, Khet Chatuchak, Bangkok 10900
Cable "POLYTHENE" BANGKOK   Telex : 72075 PETOKEM TH
Tel. (662) 649 - 7000 , 649 - 7777 , 649 - 7525 (DISA)   Fax :(662) 649-7501

SPECIFICATION

TO WHOM IT MAY CONCERN

WE HEREBY CERTIFY THAT THE UNDERMENTIONED GOODS HAVE BEEN DULY INSPECTED BY US AND THE RESULTS OF THE ROUTINE INSPECTION ARE AS FOLLOWS :

TYPE : ABS
GRADE : GA300
LOT NO. :
PACKING : 25 KGS. IN PAPER LAMINATED WITH WOVEN CLOTH BAG
QUANTITY :
DELIVERY :

ITEM	PROPERTIES	TEST METHOD	UNIT	SPEC
1	MELT FLOW INDEX	ASTM D1238	g/10min	29 - 37
2	IZOD NOTCH IMPACT	ASTM D256	kg-cm/cm	≥20
3	ROCKWELL HARDNESS	ASTM D785	R-SCALE	≥108
4	TENSILE STRENGTH	ASTM D638	kg/cm^2	≥420
5	FLEXURAL STRENGTH	ASTM D790	kg/cm2^2	≥600
6	FLEXURAL MODULUS	ASTM D790	x10^4 kg/cm^2	≥2.0
7	HDT (NON ANNEALING)	ASTM D648	°C	≥80

PATIPOL TADAKORN
ASSISTANT VICE PRESIDENT

Figure A-1 Virgin material

Figure A-2 Repelletized resin (ABS#6RP)

Figure A-3 Regrinded plastic from recycled ABS#1

Figure A-4 Regrinded plastic from recycled ABS#6

APPENDIX B

Table B-1 The physical properties of recycled ABS in the first time.

RECYCLE 0	1	2	3	4	5	AVERAGE
Melt Flow Index	36	35.6	36.8	36.2	35.4	36.0 ± 0.55
Izod Notch Impact	23.1	23.2	23.8	23.5	23.3	23.4 ± 0.28
Rockwell Hardness	110.7	110.3	111	111.4	110.9	110.9 ± 0.40
Tensile Strength	470	479	472	471	478	474.0 ± 4.18
% Elongation	10	36	12	24	38	24.0 ± 13.04
Flexural Strength	616	622	620	615	622	619.0 ± 3.32
Flexural Modulus	2.1	2.12	2.11	2.11	2.11	2.11 ± 0.01
Heat Distortion Temp	83.2	84.1	83.8	83.6	83.3	83.6 ± 0.37

RECYCLE 1	1	2	3	4	5	AVERAGE
Melt Flow Index	35	35.3	36.2	35.8	35.7	35.6 ± 0.46
Izod Notch Impact	22.5	22.6	23	22.7	22.7	22.7 ± 0.19
Rockwell Hardness	109.6	110.3	111.2	111.1	111.6	110.8 ± 0.80
Tensile Strength	467	469	466	471	467	468.0 ± 2.00
% Elongation	11	11	10	12	11	11.0 ± 0.71
Flexural Strength	620	618	617	616	619	618.0 ± 1.58
Flexural Modulus	2.12	2.11	2.12	2.11	2.12	2.12 ± 0.01
Heat Distortion Temp	82.4	82.5	82.5	82.4	82.3	82.4 ± 0.08

RECYCLE 2	1	2	3	4	5	AVERAGE
Melt Flow Index	35.1	35.2	35.8	35.4	35.6	35.4 ± 0.29
Izod Notch Impact	22.3	22.4	22.9	22.4	22.7	22.5 ± 0.25
Rockwell Hardness	109.6	110.3	109.9	110.5	110.2	110.1 ± 0.35
Tensile Strength	472	476	472	473	473	473.2 ± 1.64
% Elongation	11	10	10	10	11	10.4 ± 0.55
Flexural Strength	621	622	626	619	624	622.4 ± 2.70
Flexural Modulus	2.13	2.12	2.13	2.11	2.14	2.13 ± 0.01
Heat Distortion Temp	83.1	83.4	83	83.2	83.2	83.2 ± 0.15

<u>RECYCLE 3</u>	1	2	3	4	5	AVERAGE
Melt Flow Index	34.2	34.9	34.8	35.3	34.6	34.8 ± 0.40
Izod Notch Impact	22.3	22	22.4	21.7	22.4	22.2 ± 0.30
Rockwell Hardness	111.9	112	111.2	111.1	110.8	111.4 ± 0.52
Tensile Strength	464	465	466	472	471	467.6 ± 3.65
% Elongation	12	12	11	10	11	11.2 ± 0.84
Flexural Strength	628	619	622	624	622	623.0 ± 3.32
Flexural Modulus	2.11	2.14	2.13	2.13	2.13	2.13 ± 0.01
Heat Distortion Temp	82.5	82.6	82.9	81.8	82.3	82.4 ± 0.41

<u>RECYCLE 4</u>	1	2	3	4	5	AVERAGE
Melt Flow Index	35.1	35.8	34.9	35.1	35.3	35.2 ± 0.34
Izod Notch Impact	21.8	21.2	21.5	20.8	21.1	21.3 ± 0.38
Rockwell Hardness	109.1	109.6	109.7	109.2	108.8	109.3 ± 0.37
Tensile Strength	467	466	468	469	474	468.8 ± 3.11
% Elongation	14	10	9	9	10	10.4 ± 2.07
Flexural Strength	628	625	631	633	627	628.8 ± 3.19
Flexural Modulus	2.14	2.14	2.14	2.13	2.14	2.14 ± 0.00
Heat Distortion Temp	82.8	82.7	82.6	82.3	82.2	82.5 ± 0.26

<u>RECYCLE 5</u>	1	2	3	4	5	AVERAGE
Melt Flow Index	34.1	35.3	36.2	35.8	35.7	35.4 ± 0.80
Izod Notch Impact	20	21.1	20.9	20.2	20.4	20.5 ± 0.47
Rockwell Hardness	110.2	110.3	110.6	109.9	110	110.2 ± 0.27
Tensile Strength	469	474	475	471	470	471.8 ± 2.59
% Elongation	11	12	10	11	11	11.0 ± 0.71
Flexural Strength	630	633	638	629	631	632.2 ± 3.56
Flexural Modulus	2.14	2.13	2.13	2.13	2.11	2.13 ± 0.01
Heat Distortion Temp	82.5	83	82.8	82.4	82.5	82.6 ± 0.25

<u>RECYCLE 6</u>	1	2	3	4	5	AVERAGE
Melt Flow Index	33.5	33.9	33.7	33.6	34.3	33.8 ± 0.32
Izod Notch Impact	20.2	20.1	20	20	20.1	20.1 ± 0.08
Rockwell Hardness	110.9	110.7	111.3	110.6	111.9	111.1 ± 0.53
Tensile Strength	474	468	467	475	472	471.2 ± 3.56
% Elongation	10	10	10	11	10	10.2 ± 0.45
Flexural Strength	634	632	632	633	636	633.4 ± 1.67
Flexural Modulus	2.14	2.14	2.14	2.14	2.13	2.14 ± 0.00
Heat Distortion Temp	83.7	83.5	83.4	83.9	83.4	83.6 ± 0.22

Table B-2 The physical properties of recycled ABS in the second time.

RECYCLE 0	1	2	3	4	5	AVERAGE
Melt Flow Index	36.2	35.7	36.6	35.8	36.2	36.1 ± 0.36
Izod Notch Impact	23	23.4	23.5	23.3	23.2	23.3 ± 0.19
Rockwell Hardness	111.7	111.6	112.7	111.8	110.9	111.7 ± 0.64
Tensile Strength	476	483	479	481	480	479.8 ± 2.59
% Elongation	11	36	25	24	34	26.0 ± 9.92
Flexural Strength	615	613	614	613	611	613.2 ± 1.48
Flexural Modulus	2.08	2.08	2.07	2.07	2.08	2.08 ± 0.01
Heat Distortion Temp	85	85.7	85.8	85.7	85.6	85.6 ± 0.32

RECYCLE 1	1	2	3	4	5	AVERAGE
Melt Flow Index	34.9	35.5	36.5	35.8	35.8	35.7 ± 0.58
Izod Notch Impact	22.7	22.8	23.3	22.6	22.9	22.9 ± 0.27
Rockwell Hardness	110.4	109.9	111.2	111.7	111.6	111.0 ± 0.78
Tensile Strength	472	476	474	476	471	473.8 ± 2.28
% Elongation	12	11	12	12	13	12.0 ± 0.71
Flexural Strength	620	614	612	613	614	614.6 ± 3.13
Flexural Modulus	2.07	2.08	2.11	2.09	2.09	2.09 ± 0.01
Heat Distortion Temp	84.1	84.3	84.5	84	84.3	84.2 ± 0.19

RECYCLE 2	1	2	3	4	5	AVERAGE
Melt Flow Index	35	34.8	34.7	35.6	35.3	35.1 ± 0.37
Izod Notch Impact	22.7	22.7	22.8	22.3	22.9	22.7 ± 0.23
Rockwell Hardness	111.6	112.5	112.1	111.8	111.7	111.9 ± 0.36
Tensile Strength	479	479	482	476	476	478.4 ± 2.51
% Elongation	10	10	11	11	10	10.4 ± 0.55
Flexural Strength	618	615	616	619	614	616.4 ± 2.07
Flexural Modulus	2.1	2.1	2.08	2.09	2.08	2.09 ± 0.01
Heat Distortion Temp	85.4	86.4	84.9	86.2	85.9	85.8 ± 0.61

RECYCLE 3	1	2	3	4	5	AVERAGE
Melt Flow Index	35.9	35.6	35.8	36.1	35.9	35.9 ± 0.18
Izod Notch Impact	22.8	22.3	22.7	22.6	22.2	22.5 ± 0.26
Rockwell Hardness	111.6	112.1	111.4	111.2	110.5	111.4 ± 0.59
Tensile Strength	470	471	474	477	478	474.0 ± 3.54
% Elongation	9	10	8	8	7	8.4 ± 1.14
Flexural Strength	620	613	618	623	617	618.2 ± 3.70
Flexural Modulus	2.11	2.11	2.14	2.13	2.12	2.12 ± 0.01
Heat Distortion Temp	84.9	85	84.5	84.6	84.9	84.8 ± 0.22

RECYCLE 4	1	2	3	4	5	AVERAGE
Melt Flow Index	35.5	35.7	34.5	35.7	36.3	35.5 ± 0.65
Izod Notch Impact	22	22.1	21.5	21.7	21.5	21.8 ± 0.28
Rockwell Hardness	111.7	111.6	112.5	112.3	111.8	112.0 ± 0.40
Tensile Strength	471	472	476	474	469	472.4 ± 2.70
% Elongation	12	11	11	9	11	10.8 ± 1.10
Flexural Strength	620	620	622	618	622	620.4 ± 1.67
Flexural Modulus	2.13	2.14	2.15	2.14	2.12	2.14 ± 0.01
Heat Distortion Temp	86.8	87.3	86.6	87.8	87.2	87.1 ± 0.47

RECYCLE 5	1	2	3	4	5	AVERAGE
Melt Flow Index	34.9	35.1	35.1	34.9	34.6	34.9 ± 0.20
Izod Notch Impact	20.2	20.5	20.9	20.1	20.2	20.4 ± 0.33
Rockwell Hardness	111.9	112.3	112.5	112.2	112	112.2 ± 0.24
Tensile Strength	472	477	476	475	472	474.4 ± 2.30
% Elongation	10	11	10	10	11	10.4 ± 0.55
Flexural Strength	628	626	627	625	634	628.0 ± 3.54
Flexural Modulus	2.11	2.13	2.12	2.13	2.1	2.12 ± 0.01
Heat Distortion Temp	85.7	85.4	85.8	85.5	86.4	85.8 ± 0.39

RECYCLE 6	1	2	3	4	5	AVERAGE
Melt Flow Index	34.7	34.5	34.5	34.6	34.8	34.6 ± 0.13
Izod Notch Impact	19	18.5	19.2	19.1	18.8	18.9 ± 0.28
Rockwell Hardness	111.3	110.6	110.8	110.8	111.7	111.0 ± 0.45
Tensile Strength	471	470	469	472	469	470.2 ± 1.30
% Elongation	8	8	9	8	9	8.4 ± 0.55
Flexural Strength	635	636	633	631	634	633.8 ± 1.92
Flexural Modulus	2.11	2.14	2.12	2.12	2.11	2.12 ± 0.01
Heat Distortion Temp	85.4	85.8	86	85.9	85.9	85.8 ± 0.23

Table B-3 The physical properties of recycled ABS#6 blended with virgin ABS in the first time

VIRGIN100%	1	2	3	4	5	AVERAGE
Melt Flow Index	36.5	35.8	36.2	36.4	36.2	36.2 ± 0.27
Izod Notch Impact	23.2	23.5	23.9	23.4	23.4	23.5 ± 0.26
Rockwell Hardness	110.8	110.9	111.2	110.7	111.2	111.0 ± 0.23
Tensile Strength	479	476	475	470	472	474.4 ± 3.51
% Elongation	18	24	23	22	20	21.4 ± 2.41
Flexural Strength	615	624	625	618	624	621.2 ± 4.44
Flexural Modulus	2.11	2.1	2.12	2.11	2.13	2.11 ± 0.01
Heat Distortion Temp	83.7	84.3	83.9	83.6	83.4	83.8 ± 0.34

VIRGIN80%	1	2	3	4	5	AVERAGE
Melt Flow Index	35.7	35.2	35.9	36.4	36.2	35.9 ± 0.47
Izod Notch Impact	22.7	22.8	23.6	22.9	22.9	23.0 ± 0.36
Rockwell Hardness	111.4	112.4	111.9	111.5	112.7	112.0 ± 0.56
Tensile Strength	469	461	469	470	463	466.4 ± 4.10
% Elongation	13	17	15	16	13	14.8 ± 1.79
Flexural Strength	622	623	628	630	617	624.0 ± 5.15
Flexural Modulus	2.12	2.11	2.12	2.1	2.11	2.11 ± 0.01
Heat Distortion Temp	83.9	86	85.3	85.4	85.5	85.2 ± 0.79

VIRGIN60%	1	2	3	4	5	AVERAGE
Melt Flow Index	35.9	35.2	34.8	35.3	35.1	35.3 ± 0.40
Izod Notch Impact	22.1	21.9	22.6	22.3	22.6	22.3 ± 0.31
Rockwell Hardness	112	111.6	112.2	112.3	112.4	112.1 ± 0.32
Tensile Strength	461	458	462	463	457	460.2 ± 2.59
% Elongation	13	11	12	10	14	12.0 ± 1.58
Flexural Strength	625	631	634	628	629	629.4 ± 3.36
Flexural Modulus	2.12	2.13	2.14	2.11	2.13	2.13 ± 0.01
Heat Distortion Temp	84.5	84.8	83.8	85.2	85.5	84.8 ± 0.66

VIRGIN40%	1	2	3	4	5	AVERAGE
Melt Flow Index	34.8	34.9	35.7	34.2	34.1	34.7 ± 0.64
Izod Notch Impact	21.5	22	21.3	21.4	21.1	21.5 ± 0.34
Rockwell Hardness	111.3	111.6	111.6	111.2	111.3	111.4 ± 0.19
Tensile Strength	471	466	466	468	470	468.2 ± 2.28
% Elongation	11	11	12	11	10	11.0 ± 0.71
Flexural Strength	631	633	629	628	629	630.0 ± 2.00
Flexural Modulus	2.14	2.13	2.11	2.12	2.14	2.13 ± 0.01
Heat Distortion Temp	85.4	85.6	85.8	86.1	84.5	85.5 ± 0.61

VIRGIN20%	1	2	3	4	5	AVERAGE
Melt Flow Index	34.5	34.1	33.8	33.8	34.3	34.1 ± 0.31
Izod Notch Impact	21.5	21.2	21	20.8	21.1	21.1 ± 0.26
Rockwell Hardness	111.4	111.9	112.2	111.8	111.9	111.8 ± 0.29
Tensile Strength	464	459	457	452	460	458.4 ± 4.39
% Elongation	13	11	13	12	10	11.8 ± 1.30
Flexural Strength	628	635	633	631	637	632.8 ± 3.49
Flexural Modulus	2.12	2.14	2.13	2.14	2.13	2.13 ± 0.01
Heat Distortion Temp	82.8	83.2	83.7	83.7	82.8	83.2 ± 0.45

VIRGIN0%	1	2	3	4	5	AVERAGE
Melt Flow Index	33.7	34.2	33.5	33.9	34.1	33.9 ± 0.29
Izod Notch Impact	20.1	20.3	19.9	19.8	20.1	20.0 ± 0.19
Rockwell Hardness	111.2	111.1	110.9	110.8	111	111.0 ± 0.16
Tensile Strength	474	478	469	470	471	472.4 ± 3.65
% Elongation	12	9	10	11	10	10.4 ± 1.14
Flexural Strength	637	639	632	631	636	635.0 ± 3.39
Flexural Modulus	2.14	2.13	2.14	2.14	2.15	2.14 ± 0.01
Heat Distortion Temp	84.8	85.3	85.4	85.1	84.5	85.0 ± 0.37

Table B-4 The physical properties of recycled ABS#6 blended with virgin ABS in the second time

VIRGIN100%	1	2	3	4	5	AVERAGE
Melt Flow Index	36.2	36.9	36.7	36.8	36.1	36.5 ± 0.36
Izod Notch Impact	23.4	23.1	22.8	23.5	23.1	23.2 ± 0.28
Rockwell Hardness	111.9	111.9	112.2	112.1	112.4	112.1 ± 0.21
Tensile Strength	479	481	477	478	476	478.2 ± 1.92
% Elongation	23	25	17	29	21	23.0 ± 4.47
Flexural Strength	613	619	614	612	618	615.2 ± 3.11
Flexural Modulus	2.08	2.08	2.07	2.09	2.06	2.08 ± 0.01
Heat Distortion Temp	84.8	85.3	85.6	85.2	85.6	85.3 ± 0.33

VIRGIN80%	1	2	3	4	5	AVERAGE
Melt Flow Index	36	36.1	35.9	35.5	35.7	35.8 ± 0.24
Izod Notch Impact	23.2	23.1	23.4	22.7	22.8	23.0 ± 0.29
Rockwell Hardness	112	112	111.9	111.8	112.1	112.0 ± 0.11
Tensile Strength	467	469	464	466	465	466.2 ± 1.92
% Elongation	11	18	22	21	14	17.2 ± 4.66
Flexural Strength	621	619	623	616	617	619.2 ± 2.86
Flexural Modulus	2.1	2.08	2.09	2.08	2.09	2.09 ± 0.01
Heat Distortion Temp	86.5	86.3	85.8	86.3	86.3	86.2 ± 0.26

VIRGIN60%	1	2	3	4	5	AVERAGE
Melt Flow Index	35.5	35.6	35.9	36	35.1	35.6 ± 0.36
Izod Notch Impact	21.6	22.2	21.7	22.3	21.9	21.9 ± 0.30
Rockwell Hardness	112	111.7	112.1	111.8	112.4	112.0 ± 0.27
Tensile Strength	476	469	469	473	474	472.2 ± 3.11
% Elongation	12	13	11	9	16	12.2 ± 2.59
Flexural Strength	618	631	622	629	627	625.4 ± 5.32
Flexural Modulus	2.13	2.12	2.11	2.11	2.09	2.11 ± 0.01
Heat Distortion Temp	84.8	84.6	84.1	83.9	83.9	84.3 ± 0.42

VIRGIN40%	1	2	3	4	5	AVERAGE
Melt Flow Index	34.8	34.7	34.6	34.9	34.9	34.8 ± 0.13
Izod Notch Impact	20.1	20.6	20.9	21.1	20.6	20.7 ± 0.38
Rockwell Hardness	112	111.9	111.8	112.2	112.3	112.0 ± 0.21
Tensile Strength	467	473	476	467	464	469.4 ± 4.93
% Elongation	12	11	8	9	14	10.8 ± 2.39
Flexural Strength	627	625	626	632	631	628.2 ± 3.11
Flexural Modulus	2.13	2.14	2.14	2.12	2.12	2.13 ± 0.01
Heat Distortion Temp	85.7	84.8	85.4	84.1	85.7	85.1 ± 0.69

VIRGIN20%	1	2	3	4	5	AVERAGE
Melt Flow Index	34.5	34.6	34.1	33.9	34.2	34.3 ± 0.29
Izod Notch Impact	19.9	18.9	20	18.9	19.3	19.4 ± 0.53
Rockwell Hardness	112	112.2	111.7	112.6	111.9	112.1 ± 0.34
Tensile Strength	476	475	473	469	476	473.8 ± 2.95
% Elongation	12	11	11	12	15	12.2 ± 1.64
Flexural Strength	633	626	632	637	636	632.8 ± 4.32
Flexural Modulus	2.13	2.13	2.14	2.14	2.12	2.13 ± 0.01
Heat Distortion Temp	85.3	85.8	85.1	85	84.8	85.2 ± 0.38

VIRGIN0%	1	2	3	4	5	AVERAGE
Melt Flow Index	34.5	34.7	34.6	34.8	35	34.7 ± 0.19
Izod Notch Impact	18.9	18.5	19.2	18.3	18.4	18.7 ± 0.38
Rockwell Hardness	111	111.3	110.8	110.4	111.9	111.1 ± 0.56
Tensile Strength	471	476	468	471	465	470.2 ± 4.09
% Elongation	11	5	8	7	8	7.8 ± 2.17
Flexural Strength	634	638	637	636	634	635.8 ± 1.79
Flexural Modulus	2.13	2.14	2.14	2.13	2.14	2.14 ± 0.01
Heat Distortion Temp	84.8	84.7	85.2	84.3	84.9	84.8 ± 0.33

VITAE

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